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PHYSICAL PROPERTIES AND LEACH TESTING OF SOLIDIFIED/STABILIZED INDUSTRIAL WASTES

by

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi 39180

Interagency Agreement No. EPA-IAG-D4-0569

Project Officer

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Physical property and leaching tests were conducted to assess the engineering characteristics and pollution potential of five industrial wastes. Four solidification/stabilization processes which are under development or commercially available and represent different containment philosophies, were employed to produce four very different types of treated-waste products; one resembling low-strength concrete, one a rubber-like solid, one a solid plastic-encased block, and one a soil-like material. Physical tests used included determination of unconfined comprehensive strength, permeability, bulk density, and durability. The major environmental problem posed by these industrial wastes is the loss of inorganic constituents-heavy metals and high salt concentrations. Leach testing was conducted using continuous column leaching with CO_2-saturated, distilled water. A flow rate of 10^{-5} cm/sec was maintained for one to two years and the leachate from each column was collected and analyzed on a logarithmic schedule.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This report presents results from small-scale laboratory testing to determine the physical properties and chemical leaching characteristics of untreated and chemically solidified or stabilized industrial wastes . It provides basic data that can help estimate the potential for surface and groundwater pollution from industrial waste disposal activities and estimates of the strength and durability of the treated materials. Studies such as these provide the basis for decisions regarding disposal or productive uses of these rapidly accumulating waste materials and play a vital role in our efforts for energy independence.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

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ABSTRACT

Physical property and leaching tests were conducted to assess the engineering characteristics and pollution potential of five industrial wastes. Similar tests using the products of four solidification/stabilization processes suggest that in some cases solidification/stabilization may be a useful technique for reducing environmental pollution from these wastes. However, a great deal of work will be required to optimize treatment procedures for each waste being disposed, and additional work is required to understand the behavior of treated industrial wastes under actual field conditions.

Four solidification/stabilization processes which are under development or commercially available and represent different containment philosophies, were employed to produce four very different types of treated-waste products: one resembling low-strength concrete, one a rubber-like solid, one a solid plastic-encased block, and one a soil-like material. Physical tests used included determination of unconfined compressive strength, permeability, bulk density, and durability. All tests were conducted in triplicate. No correlation between the physical properties of the treated products and their ability to contain the sludge constituents in the leach testing was found. This resulted from the diverse containment strategies used in the different treatments. The soil-like product had the highest permeability and lowest strength and durability characteristics, but gave the best overall containment of all the solidification/stabilization products except the polyethylene-jacketed waste. The rubber-like solid which had quite high strength and durability produced leachate with by far the highest concentration of potential pollutants. The large differences in treatment strategies precluded any generalizations which might be applicable in comparing treatment processes using more similar containment technologies.

The major environmental problem posed by these industrial wastes is the loss of inorganic constituents--heavy metals and high salt concentrations. Leach testing was conducted using continuous column leaching with CO_2-saturated, distilled water. A flow rate of 10^{-5} cm/sec was maintained for one to two years and the leachate from each column was collected and analyzed on a logarithmic schedule. All tests were conducted in triplicate. Leachates from all sludges had individual samples which were higher than drinking water standards in heavy metals and anions. However, the amount of these constituents leached was generally limited by the very low permeability and high pH values of the sludges. Although the relative concentrations of the constituents lost varied greatly between the different sludge types, leachate samples from different runs with the same untreated waste sludge were quite consistent in their composition.

Results of the small-column leaching tests indicate that the average concentration of many of the constituents in the leachate were lower in leachates from the treated sludges than from the untreated control sludge columns. However, in all cases some waste constituents were lost in greater amounts from all treated waste products. Although no treatment process (other than plastic encapsulation) uniformly reduced the concentration of all potential pollutants in the leachate for all sludge types, solidification/stabilization of the waste sludges did tend to lower their pollutant potential. Reduction in the highest concentrations of sludge constituents occurring in individual sludge samples is the most pronounced effect of sludge treatment; but when the proportion of sludge solids contained in the final solidified/stabilized product is considered, the beneficial effect of sludge treatment on constituent containment is less apparent. In some cases, additional leachable materials were apparently added in the treatment process so that the losses of some constituents actually exceeded the amount of the particular constituent present in the sludge being treated. Also, some treatment processes apparently increased the solubility of certain constituents so that they were lost at higher rates from the treated sludges than from the untreated control sludge columns.

As used in this study, the small sample size (with larger waste surface-to-volume ratio), and continuous submersion in CO_2-saturated leaching solution, appear to be a rigorous leaching condition. Most landfilling operations would allow the use of much larger masses of treated sludge (with smaller surface area/volume ratios) and surface water diversion and collection systems so that saturated conditions would only occur intermittently. The conditions in an actual landfill may allow more effective containment of waste constituents in the treated wastes than found in this study.

This report is submitted in partial fulfillment of Interagency Agreement No. EPA-IAG-D-4-0569 between the U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Solid and Hazardous Waste Research Division (EPA, MERL, SHWRD) and the U.S. Army Engineer Waterways Experiment Station (WES). Work for this report was conducted during the period of October 1974 through March 1980.

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SECTION 1

INTRODUCTION

THE HAZARDOUS WASTE DISPOSAL PROBLEM

The problem of hazardous waste and what can be done with it has recently been given wide attention. In fact, the hazardous waste disposal facility has become a scare-word in most areas of the United States. The public has been sensitized to the issue by such famous and infamous examples of mismanagement as the Love Canal site in New York and the Valley of the Drums in Kentucky. A recent survey has shown that twice as many people would accept a nuclear power plant within a mile of their homes than would accept a hazardous waste disposal facility (1). This realization has also been motivation for the development and commercial application of the new waste treatment and containment technology which is the subject of this study.

HAZARDOUS WASTE TYPES

For wastes that are classed as hazardous because of an organic or inorganic compound contained in the waste, the line of action that is becoming more prevalent because of rising costs of disposal is to react, oxidize, or in some way alter the offending compound to produce a new, less toxic material before disposal is attempted. This approach which has often been used with cyanide wastes and explosive materials in the past, is now generally the most economical treatment alternative for a wide array of refractory organic compounds like polychlorinated biphenyls or kepone which can be destroyed by high-temperature incineration.

Wastes containing toxic or hazardous constituents of an elemental nature become a very different problem since, short of nuclear transmutation, no secondary treatment can alter them. In this case, if the wastes are to be disposed of, the toxic elements must be in some way contained within the waste disposal facility boundaries essentially forever, or at least losses kept so low that no harmful effects occur to the environment. The most common elemental constituents in sludges in this category are the heavy metals, many of which are toxic in very small quantities. For example, the destruction of organoarsenical wastes by incineration leaves an ash and a scrubber sludge which are high in arsenic oxides. These wastes may be very nearly as toxic and carcinogenic as the original material and often are more concentrated. A wide array of industrial wastes contain relatively high levels of heavy metals and fall into this category, making their permanent containment in the disposal area of paramount concern.

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Three sludges in this category were selected by the EPA to be included in this study largely because of their high levels of heavy metals--an electroplating waste, a nickel-cadmium battery sludge and a pigment production sludge. All of these sludges contain very high levels of toxic heavy metals in a form which is difficult to reclaim. These sludges have been traditionally disposed of largely by ponding and/or shallow land burial, or by blending with other waste for placement in municipal landfills.

A second waste type with elemental contaminants that are difficult to handle are those which contain very high levels of moderately soluble to very soluble inorganic salts. While less frightening to the public, the problem with these sludges will probably be with us longer and be more difficult to alleviate. These sludges may also contain substantial levels of toxic heavy metals which cannot be ignored, but their major impact is caused by the very high losses of inorganic salts. One type of sludge which is being produced at astounding rates at the present time is the flue gas cleaning (FGC) sludge which results from the scrubbing of sulfites from the stack gases exhausted from power plants. These sludges consist almost exclusively of calcium sulfate and contain variable amounts of heavy metals which were present in the coal. Contacting waters will become saturated in calcium and sulfate (containing 600 to 700 ppm calcium and 1250 to 1300 ppm sulfate) until the total mass of the sludge is leached away. The solidification/stabilization of five FGC sludges has been addressed in a companion study using identical physical and leach testing and many of the same solidification systems (2).

Two additional sludges are included in this study for which the loss of inorganic salts appears to be the major environmental problem--a chlorine production brine sludge and a glass etching sludge. Both have appreciable heavy metals loads which must be accounted for but also contain large proportions of soluble salts.

WASTE TREATMENT OPTIONS

Containment of waste constituents can be accomplished on several different levels (3). Technically, a 200-l drum of is a containment system even though it may not be effective for a very long period of time. Wastes can and are placed unaltered in a containment vessel or buried directly so that the landfill tested ultimately provides the containment. For smaller scale containment, the wastes can be mixed with material that will coat or "encapsulate" each separate particle or grain of the waste with an impervious, inert coating--often termed micro-encapsulation. Or perhaps the waste is merely mixed with a binder that bonds the waste particles together without necessarily coating each grain depending upon the reduction in leachable surface area to lower leach losses. The smallest scale containment systems use the production of new, inert, insoluble crystal lattices which bind the toxic elements into a durable solid material. Techniques for embedding waste materials in concrete or pozzolan concrete are well-established and currently available commercially. The solid waste material produced can be made to have high strength and relatively low rates of pollutant escape.

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The treatment materials (portland cement or flyash and lime) are commonly available.

Encapsulation of a large block of solidified waste (sometimes called "macro-encapsulation") as proposed (4) would involve fusing an impervious polymer coating to the outside surface of a large (greater than 1 cu m) monolith of waste. In some ways this approach resembles simple vessel containment such as a 200-l drum, but it is said to be more secure because the wastes are cemented into a solid form before the flexible coating is bonded to the waste.

The solidification/stabilization techniques used in this study were selected to be a representative sampling of those technologies currently commercially available or under extensive development (3). Treatment processes included are: a lime-flyash, pozzolonic cement process producing a solid, micro-encapsulation system; a cement/soluble-silicate treatment process that produces a soil-like product; an organic polymer system producing a hard, rubber-like solid; and a macro-encapsulation process which solidifies the waste and then bonds it in a polyethylene jacket. Unfortunately, not all processors elected to treat all of the five wastes included in the study, but a representative cross-section of the industrial wastes and vendor processes are available for the study.

PURPOSE OF THIS STUDY

This study was undertaken to evaluate the containment efficiency and physical properties of four different solidification/stabilization processes when applied to common industrial wastes. A complete analysis of the physical and engineering properties of the treated and untreated industrial sludges was combined with a long-term, small-scale leaching test. Comparisons were made to ascertain whether the containment success of the treatment systems could be related to any of the physical properties of the treated sludges.

SECTION 2

CONCLUSIONS

The physical and engineering properties and leaching characteristics are reported for five industrial waste sludges and the treated products made from these sludges by four solidification/stabilization processes. Data from these investigations can be used to evaluate the pollution potential of these wastes when they are disposed of in standard landfills or shallow land burial. The industrial wastes represent those whose production rate and disposal difficulty make them prime candidates for large-scale commercial solidification/stabilization treatment techniques.

The treatment processes used in this study produced final products with a wide array of physical properties varying from moderate-strength solids to a soil-like granular material. A lime-flyash pozzolonic solidification process produced a solid soil/cement-like product with good structural integrity but poor durability. Concentrations of hazardous elements in leachates from this treatment product were found at higher concentrations than in leachate from similar untreated material in about half of the cases analyzed for the four industrial sludges tested. The net benefit from treatment by this process was marginal. The cement/soluble-silicate treatment process produced a soil-like product. Physical property tests typical of structural solids could not be run on this material. Containment of constituents from the same four sludges when treated by this treatment system was better than for that containment observed for the lime-flyash product in that about three-fourths of the constituents were lost from the columns at lower rates when compared to the untreated control columns. Two sludges treated using the urea-formaldehyde formation lost most constituents at much higher rates than the control columns, possibly because of the acidification (and resulting dissolution) of the sludge that was required to produce the polymerization reaction used in this process. Urea-formaldehyde as used here appears to be counterproductive as a containment procedure. A polyethylene jacket procedure evaluated in this study gave excellent containment of all constituents except cadmium.

Replicates of the leaching tests showed remarkable repeatability between different columns using different samples of the same treatment batch from the same sludge. However, the patterns of constituent loss from different sludges treated by the same treatment process were not similar. Different waste samples processed by the same treatment system sometimes would show more, and sometimes less, loss of a particular contaminant. Since the sludges are primarily metal hydroxide waste it would be assumed that each treatment process would be more-or-less as effective in containing a particular contaminant in most of the sludge types tested. The results observed indicate that complete leaching tests might be necessary for each new waste, even though other wastes with similar constituents had previously been successfully contained by that particular treatment system.

As might be expected, the same variability was found for constituent losses from samples of the same sludge that were subjected to different treatment processes. Thus no generalizations could be made concerning the probable loss of a particular constituent either from different sludges treated by the same process, or from the same sludge as treated by different solidification/stabilization systems.

Constituents were lost to leaching from the experimental columns typically in one of two distinct patterns whether treated or not. Those constituents whose concentration in the sludge greatly exceeded their solubilities in the leaching medium (for example, calcium, nickel, lead, and sulfate) were found at relatively constant concentrations in the leachates collected over the length of the testing period. For these constituents, the rate of loss depended on the volume of leachate produced and was independent of the length of time over which the leaching took place. The second leaching pattern was seen for those constituents whose solubilities were large compared with their concentrations in the sludge (for example, chloride). These constituents had very high concentrations in the initial leachate samples, followed by an asymptotic drop in concentration as the element was depleted from the sludge that was exposed to the leaching medium. Channelization of the leachate flow in the untreated sludge columns greatly increased the rate at which the concentration of the soluble constituents in the leachate fell off, as this process lessened the area of sludge that came in contact with the leaching medium. A third, less common leaching pattern showed low initial concentrations in the early leachate samples and slow increases as the experiment progressed. This pattern was observed for constituents in which a common ion effect might limit early concentrations which increase after the levels of the interfering counterion are depleted or for constituents whose solubility increases later because of changes in pH or redox conditions in the leachate. The loss of such constituents would be missed completely in short-term leaching tests, but they may be of great consequence in the evaluation of the waste for land disposal.

The small sample size (large surface-to-volume ratio) and continuous submersion in the CO^2-saturated leaching solution used in this study, appear to represent very rigorous leaching conditions. Most landfill operations would allow the use of much larger blocks of treated sludge and would have only intermittent saturated conditions occurring in the fill. The conditions in such a landfill would thus favor the containment of the treated wastes. This study may over-estimate the leaching losses that might be expected under actual disposal conditions.

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SECTION 3

RECOMMENDATIONS

This study has shown that solidification/stabilization of potentially hazardous industrial wastes may be effective in lessening the losses of undesirable constituents to environmental waters when the wastes are disposed of by landfilling using proper engineering techniques. However, a great deal more study involving long-term and large-scale operations is necessary before the behavior of treated industrial wastes under actual field conditions can be adequately understood. Such an understanding is necessary before the disposal of industrial wastes may be carried out with the confidence that no environmental degradation will occur over the long-term.

The physical and engineering properties thought to be important in assessing the effectiveness of solidification/stabilization techniques appear to have little predictive value based upon one to two years of leaching data from this study. The wide diversity of treatment processes used with their different containment strategies, make comparison and prediction of performance from this study impractical. However, specific physical and engineering properties may be of great value in assessing the relative containment ability of treatment processes using similar technology or containment strategy. Comparisons of physical properties similar to those used here may be of great predictive value within treatments of similar type. For instance, density and unconfined compressive strength may be of critical importance to treatments which depend upon the limiting of the surface area of the waste exposed to the leaching medium; or grain-size analysis may indicate the future performance of a soluble silicate-based system.

To overcome the bias produced by the small sample size used in this study, large-scale tests using treated sludge samples more nearly typical of the surface-to-volume relationships actually encountered in monofill (single waste) landfill situations are needed. Such tests would give a more realistic estimate of treatment benefits. Intermittent saturation of the treated samples should also be considered in any future testing.

Calculation of solidification/stabilization benefits should be based upon the actual sludge solids incorporated into the treated sludge product to separate the effects of simple dilution of the waste by the treatment reagents from those actually produced by the treatment process. The estimated cost of the treatment procedures and additives should also be taken into consideration if adequate selection criteria are to be formulated.

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SECTION 4

MATERIALS AND METHODS

SLUDGE AND TREATMENT PROCESS SOURCES AND SELECTION

The industrial waste (IW) sludges used in this study are representative of those IW denoted by the Environmental Protection Agency as having a high probability of deleterious environmental effects. Their selection for this study is based largely upon their toxic composition, easy availability, and difficult handling and disposal characteristics. The sludges used represent some of the most difficult wastes to contain. As such they are good candidates for judging the effectiveness of the solidification/stabilization techniques being evaluated in this study. As all of the selected sludges are primarily inorganic in nature, the primary thrust of this work lies in the measurement of losses of inorganic ions from the treated sludges to leaching waters. This loss of inorganic constituents to surrounding ground waters constitutes the major problem encountered in IW disposal (6).

The sludges were collected directly from industrial waste streams or disposal sites in the northeastern United States. At the time of collection, the sludges were being dewatered by ponding and disposed of without further treatment. None of the wastes were being reclaimed.

Sludge Descriptions

The five sludges selected are inorganic sludges with dangerous levels of toxic, heavy metals, and/or other leachable ions, but with only traces of organic materials. All are difficult to dewater and represent problems for disposal. High U. S. production levels and lack of reclamation facilities placed these wastes in a category of problem sludges. A comparison of their major characteristics and constituents, along with the identification number used in this study, are shown in Table 1. All of the sludges have appreciable levels of calcium which come from neutralization processes and/or treatment with lime to precipitate the heavy metals. The anions present at high levels in all sludges are chloride and sulfate. All are alkaline and have percent solids between 25 and 60.

The electroplating sludge (No. 200) contains waste from phosphatizing and metal cleaning operations, and solids from the treatment of spent plating liquors. The plating solutions containing chromates are acidified, treated to reduce chromates to trivalent chromium with sulfur dioxide or sodium metasulfite, and then raised to pH 8.0 with sodium or calcium hydroxide to precipitate the trivalent chromium as $Cr(OH)_3$. The cyanide plating

TABLE 1. MAJOR CHARACTERISTICS AND CHEMICAL CONSTITUENTS OF SLUDGES INCLUDED IN THIS STUDY

Sludge description	Ident. no. this study	Annual production (metric tons, wet)	% Solids	Density (kg/m^3)	pH	Constituents >10,000 mg/kg (dry)	Constituents 100-10,000 mg/kg (dry)	Constituents 1-100 mg/kg (dry)
Electroplating sludge	200	50	32	1266	7.6	Ca, Cr, Cu, Fe, SO_4, Cl, Si	Be, Cd, Pb, Mg, Mn, Ni, Zn	As, Hg
Nickel-Cadmium battery	300	100	40	1250	12.3	Ca, Ni, Cl, Si	Cd, Cr, Cu, Fe, Pb, Mg, Mn, Zn	As, Hg
Pigment production sludge	700	17,000	25	1170	8.4	Ca, Cr, Fe, Pb, Mg, SO_4, Cl, Si	As, Cd, Cu, Mn, Ni, Zn	Hg
Chlorine production brine	800	3,000	59	1570	9.5	Ca, SO_4, Cl, Si	Cu, Fe, Mg, Mn, Ni, Zn, Hg	As, Cd, Cr, Pb
Glass etching sludge	900	2,000	47	1410	8.3	Ca, SO_4, Cl, Si	Cu, Fe, Pb, Mg, Mn, Ni, Zn	As, Cd, Cr, Hg

liquors are treated with sodium hydroxide and chlorine gas or sodium hydrochlorite to oxidize the cyanide. The metals present, such as cadmium, copper, and zinc, are precipitated as hydroxides. This sludge is quite alkaline as a result of the addition of lime or caustic.

The nickel-cadmium battery production sludge (No. 300) is produced during the precipitation of the nickel and cadmium from nitrates in forming the electrodes for batteries. The precipitation takes place as the pH of the solution of metal salts is raised to 11 or 12 with sodium hydroxide. The excess $Cd(OH)_2$ is washed off. This wash plus the material which is remaining in suspension from the spent salt solution settle to form the sludge. The pH of this sludge is very high--over 12. Although sludges 200 and 300 are produced in lower quantity than the other sludges, their high heavy-metal-load makes the magnitude of their disposal problem comparable to or even greater than the others.

The paint pigment sludge (No. 700) is produced in a waste treatment system that neutralizes waste water with $Ca(OH)_2$, and adds Na_2S to precipitate metals and a polymer to aid settling. Ferrous sulfate is then added to remove excess sulfide and the waste water run through a clarifier to remove solids. This sludge is also moderately alkaline and was the lowest percent solids and density of the five sludges. This sludge is produced in the greatest volume of any of the sludges tested.

The chlorine production sludge (No. 800) consists primarily of material present as impurities in rock salt, the salt is dissolved to form brine and impurities (calcium sulfate, calcium carbonate, and other less soluble materials) are left as a sludge in the brine saturator. This sludge constitutes 80 percent of the total chlor-alkali plant sludge. The additional 20 percent is produced in treating the spent liquor from the mercury cell before recycling. The blended sludge contains calcium sulfate and calcium carbonate along with other metal carbonates and some sodium hydroxide. The pH of the sludge is high due to the presence of NaOH. This sludge has the highest percent solids and density.

The glass-etching sludge (No. 900) consists of solids from a neutralization and treatment plant. Calcium hydroxide is added to the wastewater and a sludge forms that contains 20 percent $Ca(OH)_2$, 8 percent calcium fluoride, 8 percent calcium silicates and silica, 3 percent calcium sulfate, and 2 percent aluminum oxide and hydroxide. Organic domestic wastes (3 percent) and water comprise the remainder of the waste. The excess $Ca(OH)_2$ added in treatment keeps the pH high.

Selection of Sludge Processors

Four waste processors from the list provided by the EPA agreed to take part in the test program on solidification/stabilization of the IW sludges included in the study. The processors are identified only by letter throughout this study to protect their anonymity. The processors and the sludges they evaluated and/or treated are listed in Table 2.

TABLE 2. LISTING OF IDENTIFICATION CODES OF PROCESSORS THAT EVALUATED AND/OR TREATED EACH INDUSTRIAL WASTE SLUDGE

Sludge Type	Identification Number This Study	Treated by Processors
Electroplating	200	A, B, C, D
Ni-Cd battery	300	A, B, (C)*
Pigment production	700	C, (A), (B)
Chlorine production brine	800	A, B, (C)
Glass etching	900	A, B, (C)

Note: Processors are listed by code letter only; a generic description of each treatment process is given in the text.

* Parentheses indicates sludge evaluated by processor but not treated for this study.

The processors were furnished a sample of each of the test sludges for the purpose of optimizing their treatment system to each waste. This preliminary evaluation allowed the processor to establish the best admixture ratios and make preliminary leach and strength tests of their treated products. The results of these processor tests are discussed in the section on stabilizing techniques. After this initial testing, processors A and B declined to treat the pigment production (No. 700) sludge, and processor C declined treatment of the Ni-Cd battery sludges (No. 300), the chlorine production brine sludge (Nc. 800) and the glass etching sludge (No. 900). Processor D initially agreed to treat all five waste types, but ultimately confined its effort to only one sludge, the electroplating waste (No. 200), for economic reasons.

STABILIZATION TECHNIQUES

Following the preliminary evaluation by the processors, the participating vendors in the program treated sludge samples for laboratory evaluation

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and physical testing at WES. This arrangement was made to allow WES project personnel to observe the actual treatment procedure and to assist where necessary in preparing test specimens. All solidification procedures included within the program required a curing time for their product. At the end of the curing time, the processors were invited to certify that the treatment was adequate, and in some cases, to prepare additional samples for testing.

Samples of the raw sludges obtained for this study were well mixed and then split into several subsamples. One portion was used for preliminary evaluation by the processors, a portion was used for raw sludge chemical and physical testing, a portion was utilized for the actual sludge treatment, and the remainder retained for supplementary testing. Sludge samples were mixed in a large blade mixer in required batch sizes to insure uniformity.

Solidification/stabilization processes used in the project generated products which could be classified into two specific groupings: the first was a soil-like material which was highly variable in particle size; the second was a solid, monolithic material. The procedures used for the first group required pouring the treated sludge in square molds (122 × 122 × 9 cm). The molds were covered for curing. Physical testing was done on square samples but the leached samples were broken into smaller sizes (about 5 cm in the largest dimension). These broken pieces were loaded into the leaching columns without any bead-packing around the waste (see below). The second group of samples (monoliths) was molded in 7.6 cm diameter, paraffin-lined tubes which were 122 cm in length. Shorter tube lengths were used in some cases for convenience. After curing, the tubes were removed and the resultant solidified cores placed with packing beads in the leaching columns for leach testing or subjected to physical testing. Any deviation from these procedures is noted in the detailed description below.

The actual procedures used for solidification of the industrial waste sludges are proprietary, but general comments can be made about each system. All weights presented for sludges in the Table 3 and are wet weights and weights for compounds used by the processors are given as supplied by the individual processors.

Process A - Process A, which is patented, uses flyash and a lime additive to produce a pozzolan product. This processor treated all sludges except 700. Bituminous flyash is used for the industrial sludges with the amount of flyash added related to the amount of total solids in the waste being treated. A final product with a high solids content (around 80 percent) is considered optimum and dewatering the sludge often reduces the amount of flyash required. All sludges that could be dewatered by settling and decantation were dewatered at WES.

The sludge and fixation agents were mixed in a 0.14 cu m (5 cu ft) mortar mixer. The fixed product was then placed into cylindrical molds, covered, and allowed to cure for 30 days. Subsequent inspection of the fixed specimens revealed that curing in the molds under dry conditions had produced cracks, a situation which the processor felt was not representative of this process. Due to time limitations, a second solidification was performed at the processor's laboratories. In this case, the specimens were placed in shorter tubes (7.6 cm × 40.6 cm) and cured under humid conditions to prevent cracking. The fixed specimens were then shipped to WES for chemical and physical testing. This processor chose not to reveal the specific additive to sludge ratios; however, the percentage of dry sludge solids for each fixed specimen in presented in Table 3.

The small batch and mold size required for this study required mixes slightly different from larger scale preparations. In a field scale operation, placement and consolidation of the sludges is commonly done with construction equipment which requires a stiffer, lower moisture-content mix.

Process B - Process B, which is also patented, uses two additives to produce a material of "soil-like" consistency. The relative proportions of reagents in the final mix determines the physical properties of the treated product. The consistency of the end product can be determined either by the amount of reagents needed to effect pollutant immobilization, or by the amount needed to effect a consistency necessary for the ultimate use of the fixed sludge. In most cases for stabilizing waste for landfill disposal, an soil-like material, which is most economical end product, is produced.

The sludge was mixed in 35 to 50 liter batches using an industrial propeller mixer. This provided mixing equivalent to that produced by the processor's equipment which includes an aerated, continuously stirred reactor and a series of recirculating and transfer pumps designed to provide complete mixing of the sludge and reagents. A type of cement was added at a rate proportional to the weight of the sludge. Then a soluble silicate was added slowly to the mixture and the mixture blended until uniform. Finally, lime was added when necessary to raise the pH to around 7. Molds 122 cm square by 9 cm high were used to hold the fixed sludge for curing. A polyethylene cover was put over the samples during the 12-day curing period to prevent excessive drying. The fixed specimens were broken into irregular chunks, 2 to 5 cm in dimensions and placed in the leaching columns without compaction. All sludges except No. 700 were treated. The percent dry sludge solids, weight of sludge loaded in the column, and the weight of dry sludge in the column for the four sludges fixed are given in Table 3.

Process C - Process C uses an organic resin, urea-formaldehyde plus a catalyst solution (sodium bisulfate) in a polymerization process. Cross-linking of sludge and resin mix requires an acidic medium which is provided by addition of $NaHSO_4$. For this study the reagents were manually mixed with the sludge using a paddle stirrer. The mixture was immediately poured into cylindrical molds and allowed to cure. Fixation was performed on sludges No. 200 and No. 700 only and the formulations used appear in Table 3.

Process D - Process D is an encapsulation method utilizing a resin to form an agglomerate with the waste. This solid product is subsequently surrounded by a 0.64 cm plastic jacket which is fused to the agglomerate. The process requires a dry residue for treatment which was provided by WES to

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TABLE 3. FORMULATION AND LEACHING COLUMN LOADING FOR INDUSTRIAL SLUDGES

Sludge Number	% Dry sludge solids in product	Wt fixed product in column (g)	Wt dry sludge (g) solids in column
Untreated sludges			
200R	37	12305	4510
300R	45	13800	6150
700R	41	11720	4830
800R	61	15480	9500
900R	47	13950	6570
Processor A			
200A	25	7385	1850
300A	21	8500	1785
800A	41	8390	3440
900A	37	7060	2610
Processor B			
200B	33	7260	2370
300B	40	8135	3260
800B	55	9360	5180
900B	--	--	--
Processor C			
200C	25	6410	1570
700C	26	5590	1440
Processor D			
200D	50	2505	1250

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the processor's laboratory. Actual treatment was performed at the processor's facility because of the specialized equipment needed to solidify and encapsulate the samples. Only samples of the electroplating sludge (No. 200) were treated using this process. The finished product was an agglomerate containing 96-97 percent dry sludge and 3-4 percent treatment reagent (organic binder) inside a 0.6 cm polyethylene jacket.

The encapsulated samples provided to WES were cylindrical in shape, 7.6 cm in diameter and 10.2 cm in height; each contained approximately 250 g of dry residue. These cylinders were used as received for all chemical and physical testing.

Photographs of untreated and treated sludge samples are shown in Figures 1 to 5. The treated sludges appear in the form in which they were loaded into the leaching columns. Note that Processes A, C, and D produced excellent cylindrical shapes. The material from Process B is shown in chunks as broken from the large samples supplied by the vendor.

The primary concern in ultimate disposal of hazardous industrial sludges is the rate of pollutant migration into the groundwater around the wastes. Therefore, the leaching columns used in this experiment are designed to simulate leaching from sludges buried in a saturated, unlined landfill. This leaching test is aimed at measuring the rate of pollutant movement into an aqueous medium under conditions simulating those encountered in the field.

The materials chosen for construction of the columns were those considered to be inert with respect to the test specimen and leachates. Because adequate information was not available regarding pollutant interaction with materials in this study, only the highest grade plastics were chosen for construction materials.

The leaching columns (Figure 6) were made from 152.4 cm lengths of 10.2 cm (inside diameter) plexiglass pipe. The inlet port was located 19.0 cm below the top of the column, providing space for a fluid head of 2.5 cm on top of the sample. The tops of the columns were covered to minimize contamination by dust from the air. The volume of these columns is approximately 10 l. The columns were sealed with a Teflon stopcock at the lower end and contained a perforated plate above the stopcock, leaving a 2.5 cm deep collecting well. The Teflon stopcock served as an outlet port for collection of leachate. A 7.6 cm layer of 0.65 cm diameter polypropylene pellets was placed in the bottom of the columns to slow movement of the sludge into the collection system. Flow through the column was regulated by the Teflon stopcock to maintain a fluid velocity of approximately 1×10^{5} cm/sec (to simulate the leachate flow-rate through a fine sand). Leachate was allowed to drain into 4.5 l polypropylene containers which were covered with plastic film to keep out dust.

The solidified sludges which set up into a definite physical shape and demonstrated structural rigidity were molded into 7.6 cm diameter cylinders 121.9 cm in length. These samples were placed into the leaching columns and

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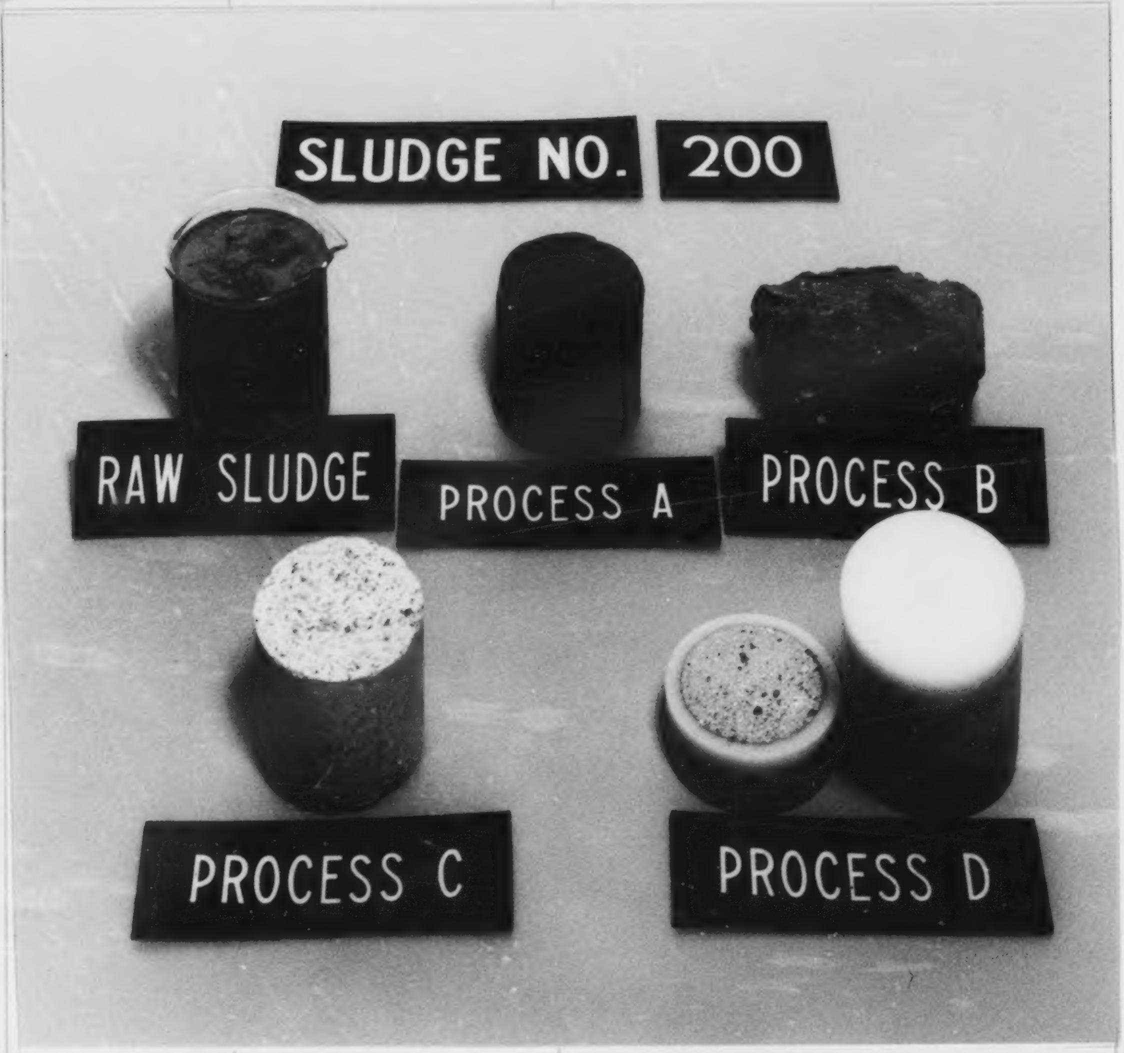
SLUDGE NO. 200
RAW SLUDGE
PROCESS A
PROCESS B
PROCESS C
PROCESS D

Figure 1. Untreated (raw) and solidified electroplating wastes (No. 200).

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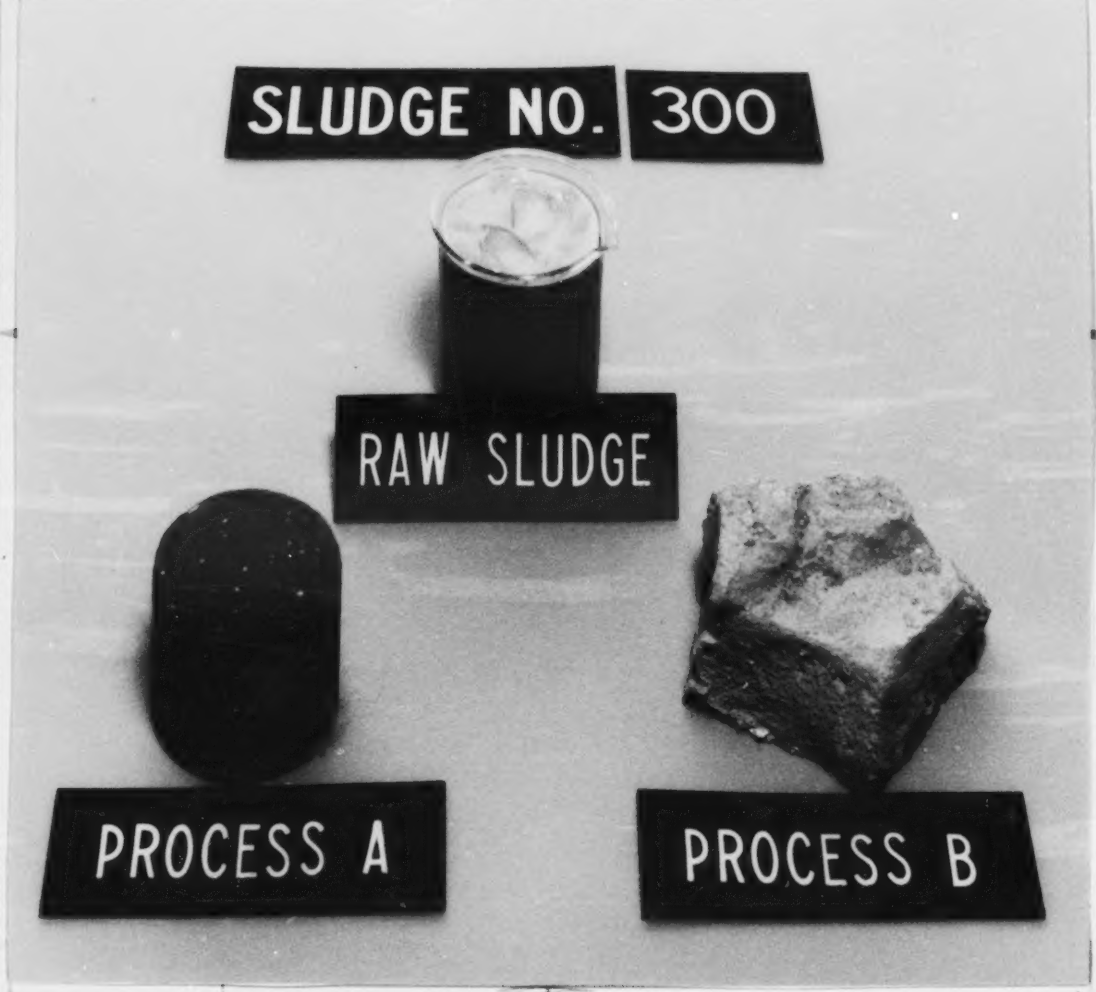
SLUDGE NO. 300
RAW SLUDGE
PROCESS A
PROCESS B

Figure 2. Untreated (raw) and solidified Ni-Cd battery sludge (No. 300).

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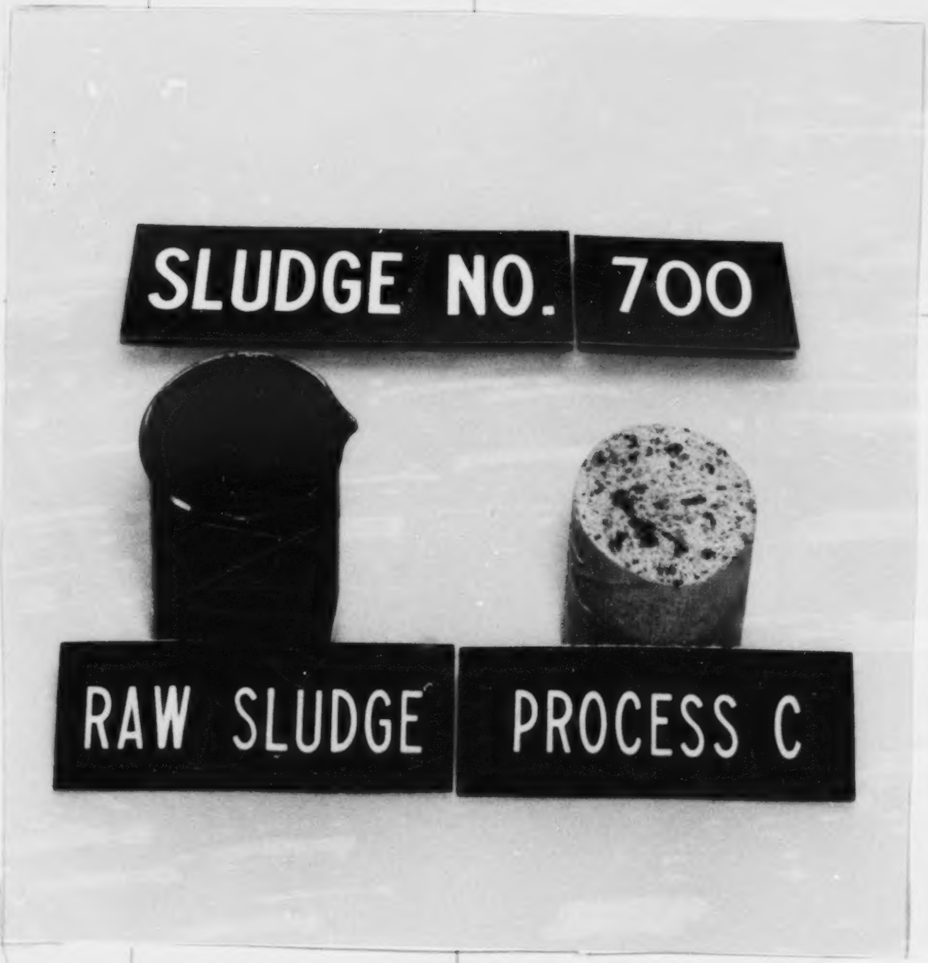

Figure 3. Untreated (raw) and solidified pigment production sludge (No. 700).

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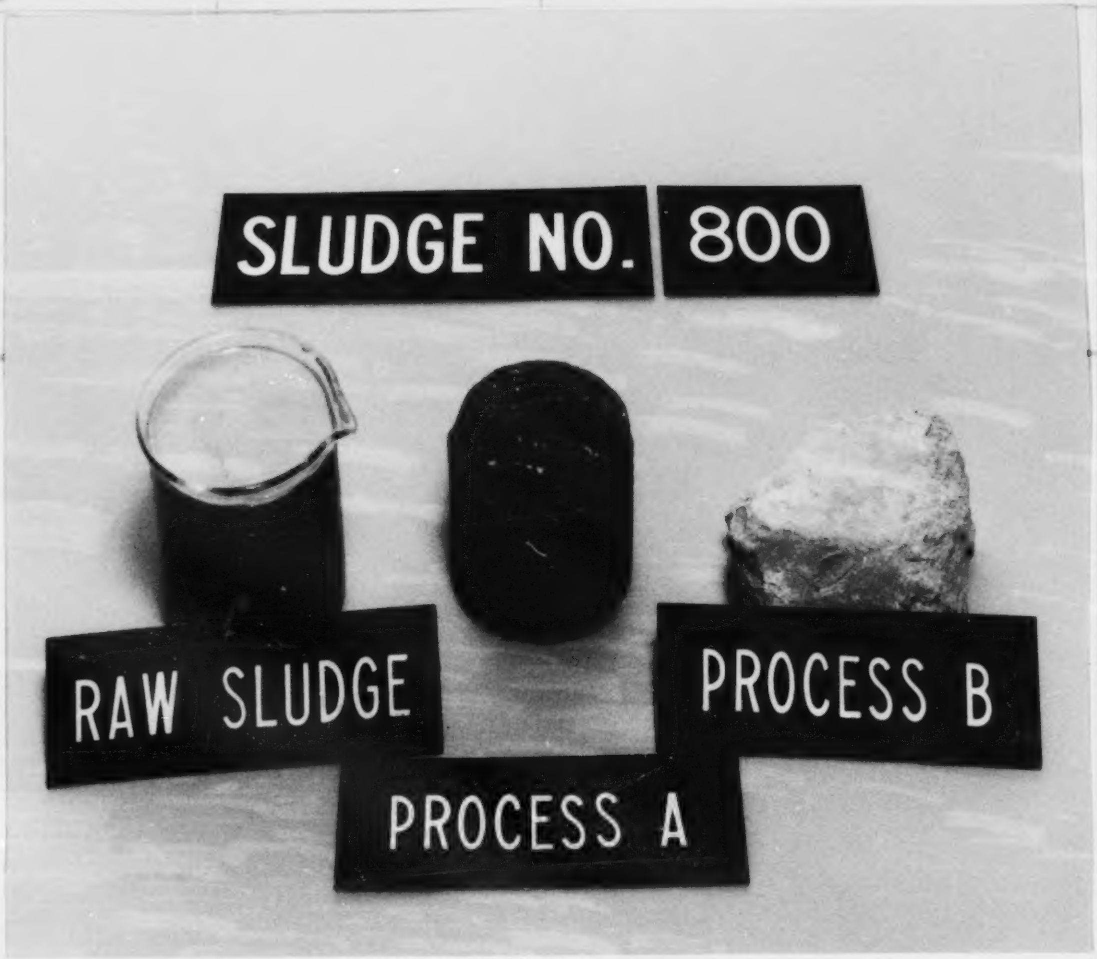
SLUDGE NO. 800
RAW SLUDGE
PROCESS B
PROCESS A

Figure 4. Untreated (raw) and solidified chlorine production sludge (No. 800).

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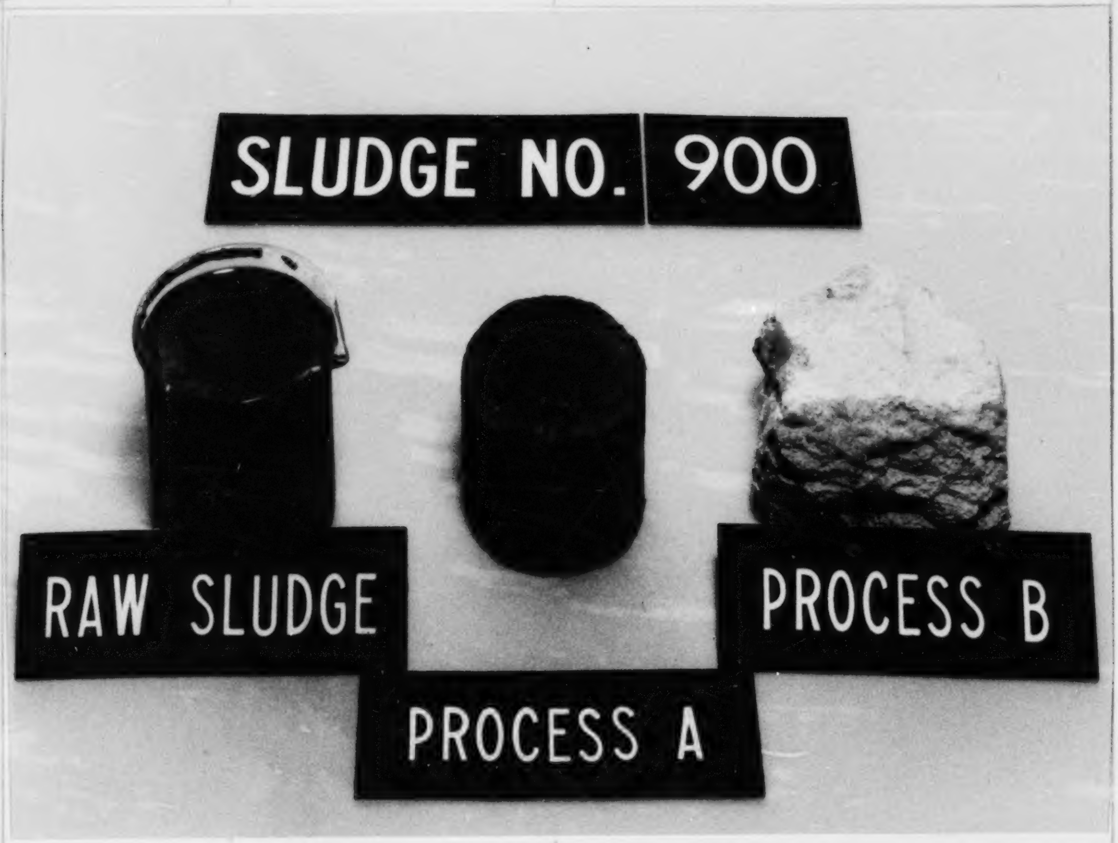
SLUDGE NO. 900
RAW SLUDGE
PROCESS B
PROCESS A

Figure 5. Untreated (raw) and solidified glass etching sludge (No. 900).

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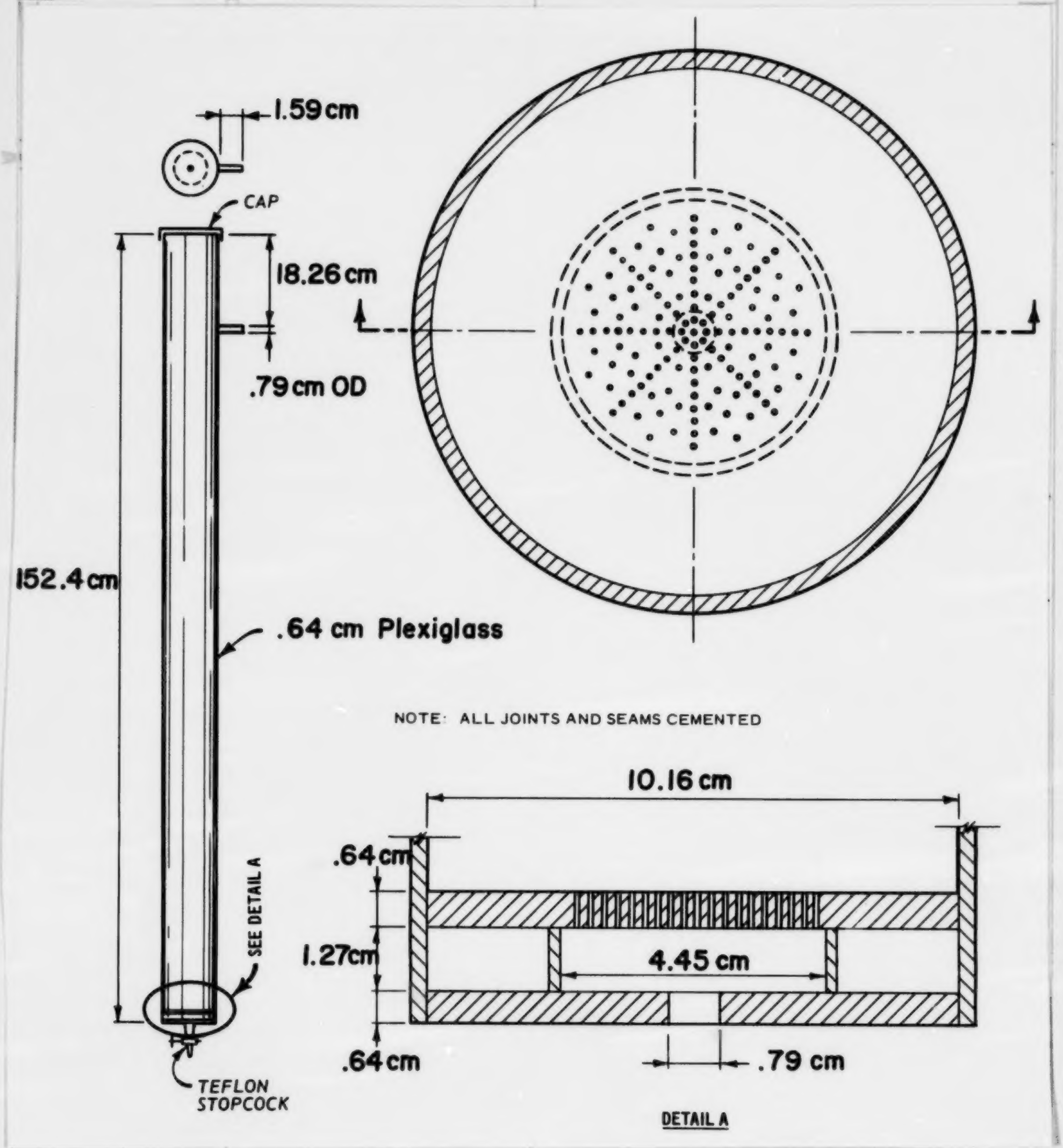
1.59 cm
CAP
18.26 cm
.79 cm OD
152.4 cm
.64 cm Plexiglass
SEE DETAIL A
TEFLON STOPCOCK
NOTE: ALL JOINTS AND SEAMS CEMENTED
10.16 cm
.64 cm
1.27 cm
4.45 cm
.64 cm
.79 cm
DETAIL A

Figure 6. Leaching column design and detail.

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the space between the sludge and the column wall (1.25 cm) filled with polypropylene pellets. This created a dispersed flow around the outside of the solidified waste similar to field conditions. The solidified sludges which could not be molded into the cylindrical shape were broken into smaller pieces as previously described and loaded into the columns. The raw sludges were poured into the columns in a slurry. In all cases, leaching fluid was backflooded into the columns from the bottom to remove any air spaces, and the specimens were maintained in a saturated flowing condition. All sample columns were set up in triplicate, one of which was selected for special low-level analysis of heavy metals in the leachate. The selected columns are referred to as priority columns.

The leaching fluid used in the experiments was deionized water saturated with CO_2 which had a pH 4.5-5.0. All materials used in the leach fluid distribution system were either polypropylene or Teflon to minimize any contamination of the leaching fluid during the experiment. The leaching columns were randomly assigned within a rack system (see Figure 7). Leaching fluid for each rack of columns (30 columns per rack) was fed from a constant head reservoir which was connected to a main reservoir of CO_2-purged leaching fluid.

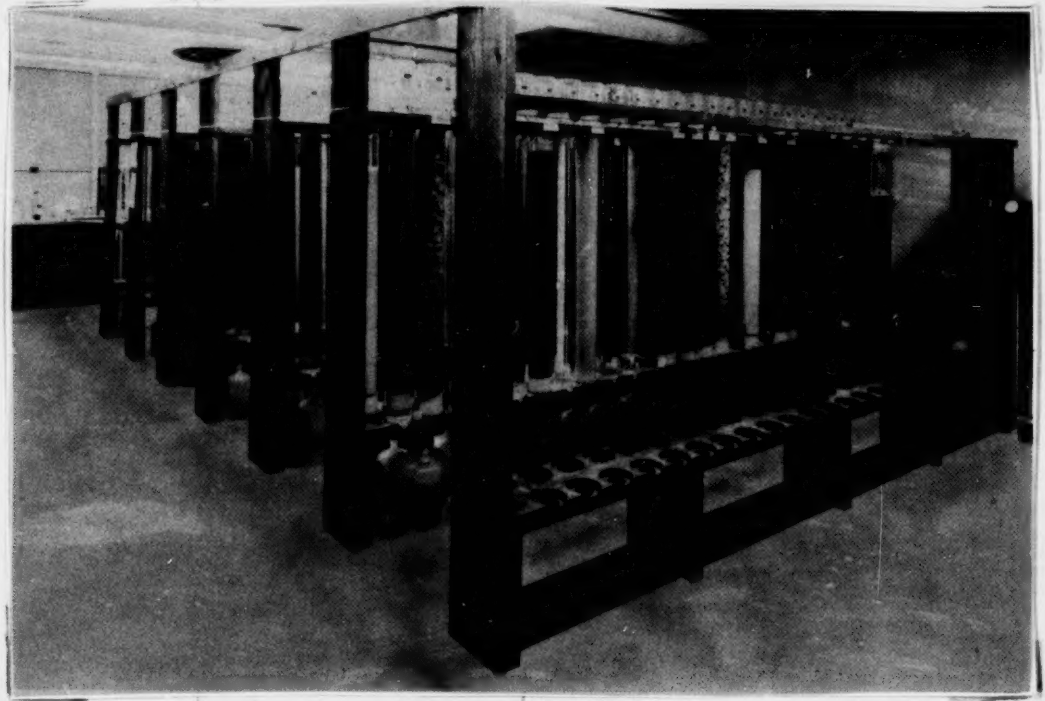

Figure 7. Leaching columns in place in racks.

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Two types of experimental controls were incorporated into the leaching test. One type of control consisted of columns of raw sludges which were leached in the same fashion as the treated sludges. The second type of control utilized leaching columns with only the polypropylene beads. The leaching fluid was sampled periodically and corrections made for any background effects of the leaching fluid, polypropylene and column apparatus.

Prior to loading the columns with samples, all materials were washed with a laboratory detergent and rinsed with diluted HCl. The entire leaching apparatus was preleached for one week at the design flow rate. No provisions were made to retard biological activity within the leaching apparatus.

CHEMICAL ANALYSIS

All samples of leachate from the columns were collected in 4.5 l plastic bottles. After the pH and conductivity and volume was measured at each sampling time, the samples were split into aliquots of appropriate size. Each aliquot was preserved as required for each set of analysis as described in Table 4. All samples were held at 4°C until analyzed. For samples of volume too small to make all analyses, subsamples were first made for metal analysis, then anion and cyanide analysis, and then total organic carbon and chemical oxygen demand. Specific analyses made for nonmetal parameters and their limits of detection are listed in Table 5. Of the three replicate columns for each sludge type and solidification process, one was selected at random for high-resolution metal analysis (priority column). The remaining two replicates were analyzed using low resolution metal analysis (flame atomic absorption). The limits of detections for these two levels of analytical techniques are shown in Table 6. These parameters were selected to describe the chemical properties of the treated and untreated sludge column leachates and included all pollutants of specific interest.

TABLE 4. SAMPLE PRESERVATION FOR CHEMICAL ANALYSIS*

Parameter	Method
Metals (cations)	Ultrex nitric acid
Cyanide	Sodium hydroxide
Total organic carbon	Hydrochloric acid
Chemical oxygen demand	Sulfuric acid
Anions	None

* From Methods of Chemical Analysis of Water and Wastes, No. EPA-625/6-74-003, U. S. Environmental Protection Agency, Washington, D. C., 1974.

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TABLE 5. METHOD OF ANALYSIS FOR ANIONS AND OTHER PARAMETERS AND THEIR LIMITS OF DETECTION

Parameter	Method of Analyses	Limit of Detection (ppm)
Total Organic Carbon (TOC)	Dohrmann DC-50, Carbon Analyzer*	1
Chemical Oxygen Demand (COD)	Technicon Analyzer**	5
Chloride	Manual Titration**	5
Cyanide	Technicon Analyzer†	0.01
Mercury	Zeeman Atomic Absorption	0.002
Nitrite-N	Technicon Analyzer*,**	0.01
Nitrate-N	Technicon Analyzer*,**	0.01
Sulfate	UV-Visible Spectroscopy*,**	8
Sulfite	Manual Titration*,**	3

* Methods for Chemical Analysis of Water and Wastes, EPA-625/6-74-003, U. S. Environmental Protection Agency, Washington, D. C., 1974.

** Standard Methods for the Examination of Wastewater, 13Ed, Am. Public Health Assoc., Washington, D. C. 1971.

† Cyanide in Water and Wastewater, Technicon Industrial Method No. 315-74W, Technicon, Comp., 1974.

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TABLE 6. LIMITS OF DETECTION FOR METALS IN LOW RESOLUTION SAMPLES ANALYZED BY FLAME ATOMIC ABSORPTION AND HIGH RESOLUTION SAMPLES ANALYZED BY HEATED-GRAPHITE-ATOMIZER ATOMIC ABSORPTION

Metal	Low Resolution (ppm)	High Resolution (ppm)*
As	2.0	0.005
Be	0.05	0.005
Ca	0.2	**
Cd	0.05	0.003
Cr	0.5	0.003
Cu	0.2	0.003
Fe	0.3	0.003
Pb	1.0	0.002
Mg	0.02	**
Mn	0.1	0.002
Ni	0.3	0.005
Se	1.0	0.005
Zn	*	0.014

* High resolution analysis was made only for samples from "priority columns." See text.

** None reported.

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Leachate samples were collected from each of the columns at logarithmic time intervals for a minimum of one year. Twelve samples were taken at 7, 14, 21, 28, 42, 56, 86, 116, 146, 206, 266, and 365 days. This sampling schedule was selected as the best fit of leaching column performance as predicted by mass transport theory (7). Mass transport theory specifies a diffusion mechanisms between the material surface and the leaching solution. Although other reactions are occurring, the data represent an "effective" diffusivity for a given pollutant. Leaching systems are generally characterized by a stable or decreasing leach loss rate which approaches some limiting value usually near zero. For this reason, the initial sampling periods were deemed more critical and the columns were sampled using logarithmic sampling intervals.

An extensive quality control program was implemented to assure precision and accuracy within the analytical program. Internal, intralaboratory and extralaboratory procedures were used. The internal program included replicate determinations and spiked additions to representative samples; the intralaboratory program used spiked and reference samples within the column leachate samples; and the extralaboratory program was coordinated between the Analytical Laboratory Group of WES and the USEPA in Cincinnati, Ohio. The extralaboratory program primarily concentrated on metals since they represent the major group of pollutants in the project.

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SECTION 5

PHYSICAL AND ENGINEERING PROPERTIES OF TREATED AND UNTREATED INDUSTRIAL WASTES

A description of laboratory tests used to determine the physical properties of treated and untreated industrial sludges, and the results of those tests, are the subject of a separate report (8) and are only summarized here.

Tests commonly used in determining the properties of soil and concrete were performed on treated and untreated sludges to determine their physical and engineering properties. The use of standard tests allowed comparison of sludge properties with those of common industrial and construction materials whose properties are described in the literature. The treatment processes used produced solidified wastes with three different characteristics; Process B produced treated materials which were similar in appearance to cemented soil, Processes A and C resulted in hard materials resembling low strength concrete, and Process D coated the solidified sludges with a plastic jacket so that many of the physical properties tests were not applicable to it. Procedures used to test treated and untreated sludges were selected on the basis of the appearance of the materials (i.e., soil-like or solid). The testing schedule is shown in Table 7. Standard test procedures were modified as necessary to prevent the alteration of sludge properties during testing and to accomodate the non-standard test specimens. Specific deviations from standard procedures are described where appropriate.

PHYSICAL PROPERTY TESTS AND RESULTS

Grain Size Analysis

The particle-size distributions of samples of untreated sludges were determined by two grain-size analysis tests and these results were combined. A sieve analysis was performed on that fraction of each sludge sample larger than 0.074 mm (No. 200 sieve), and a hydrometer analysis was performed on the finer fraction. Test procedures are described in Appendix V of Engineering Manual (EM) 1110-2-1906 (see Reference 9) and in the American Society of Materials (ASTM) Standard Test D422-63 (see Reference 10). Samples for grain-sized distribution testing were prepared in accordance with the specifications of ASTM D421-58. The grain-size distributions are presented in Figures 8 to 11, as grain-size in millimeters versus percent fines by weight.

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TABLE 7. TEST SCHEDULE FOR TREATED AND UNTREATED INDUSTRIAL WASTE SLUDGES

Type of Test	Untreated Sludges	Treatment Processes*			
		A	B	C	D
Grain-size analysis	X		X		
Specific gravity of solids	X	X	X	X	X
Water Content	X	X	X	X	X
Bulk and dry unit weight	X	X	X	X	X
Porosity and void ratio	X	X	X	X	X
Liquid limit	X		X		
Plastic limit	X		X		
15-blow compaction test	X		X		
Unconfined compression test		X	X	X	X
Permeability test	X	X	X	X	X
Freeze-thaw test		X	X	X	X
Wet-dry test		X	X	X	X

* The sludge types treated by each processor are listed in Table 2.

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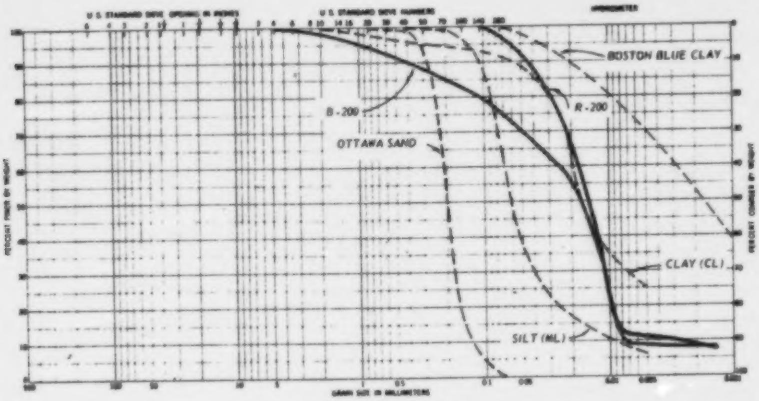
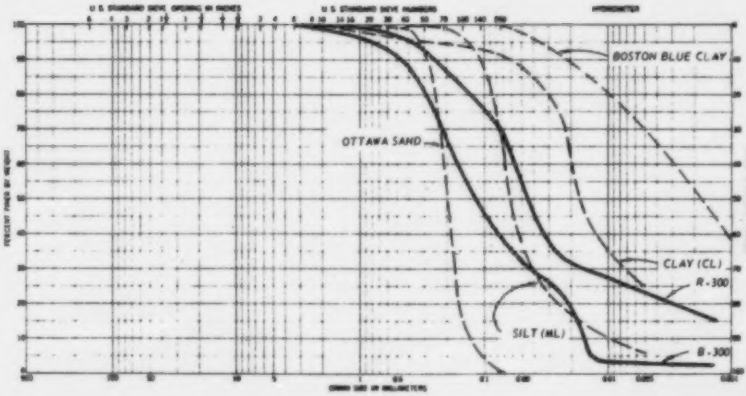


SLUDGE 200

Figure 8

Figure 8. Grain-size distribution for untreated electroplating (No. 200) sludge.



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SLUDGE 300

Figure 9. Grain-size distribution for untreated Ni-Cd battery (No. 300) sludge.

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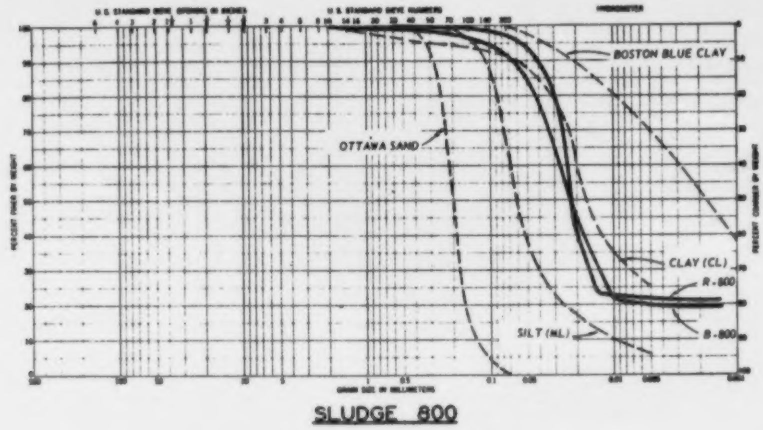

Figure 10. Grain-size distribution for untreated chlorine production sludge (No. 800).

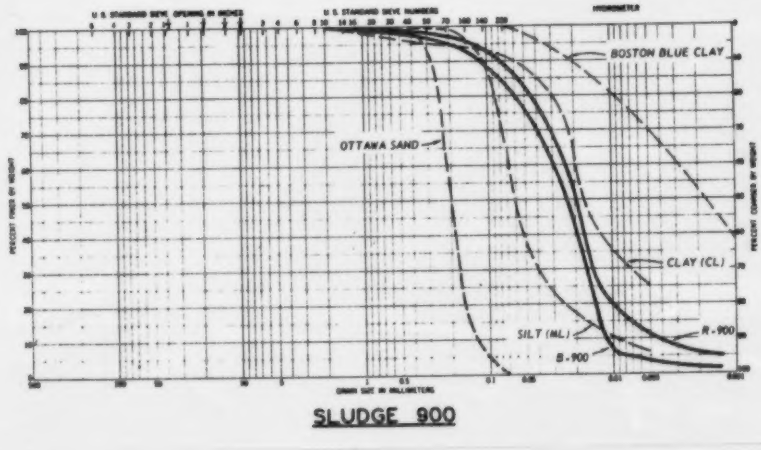

Figure 11. Grain-size distribution for untreated glass etching sludge (No. 900).

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Median grain-sizes of the untreated IW sludges, as determined by the grain-size analysis, ranged uniformly between 0.015 and 0.044 mm. The sludges were generally well-graded with a continuous distribution of grain-sizes. A high-percentage of particles of the untreated sludges (90 percent or greater in all IW sludges, except sludge No. 300) passed the No. 200 sieve (0.074 mm) indicative of materials displaying low permeability, low strength, and high compressibility.

Specific Gravity of Solids

Specific gravity of solids for treated and untreated sludges is defined as the ratio of the unit weight of the dry sludge solids to the unit weight of water. The test procedures used to determine the specific gravity are given in Appendix IV of EM 1110-2-1906 (9) and in ASTM D854-58 (10). Tests were first performed using an oven at a drying temperature of 110 ± 5°C. However, due to loss of water of hydration at this temperature, tests were repeated using a drying oven temperature of 60°C.

The specific gravities of treated and untreated IW sludges are presented in Table 8. Values varied from 2.41 to 3.96--a range extending somewhat higher than that of typical soils. In general, the various treatment processes caused only slight changes in specific gravity. Process A resulted in lower specific gravity values for all sludges treated. Process B caused small and variable changes, resulting in values both slightly higher and lower than the values of corresponding untreated sludges. Process C reduced the specific gravity of sludges No. 200 and No. 700 significantly --

TABLE 8. SPECIFIC GRAVITIES OF TREATED AND UNTREATED INDUSTRIAL WASTE SLUDGES

Sludge Number	Specific Gravity				
		Treatment Process			
	Untreated	A	B	C	D
200	2.70	2.49	2.73	1.77	1.18*
300	3.96	2.71	3.68	NT	NT
700	3.09	NT**	NT	1.74	NT
800	2.82	2.67	2.84	NT	NT
900	2.76	2.58	2.73	NT	NT

* Bulk specific gravity of entire cylinder of fixed sludge, including plastic coating and voids within sludge structure.

** NT = sludge not treated by that processor. See Table 2.

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values being 34 percent and 51 percent lower respectively than those of the corresponding raw sludges. The use of dried sludges by Process D is indicated in its lower specific gravity product. This effect is caused by voids in the dried sludge. In general, changes in specific gravity did not seem to be dependent on the type of sludge being treated.

Water Content (Dry Weight Basis)

The water content of the sludge sample is defined as the ratio of the weight of water to the weight of solids in the sample and is normally expressed as a percentage. Calculated in this way, it is termed "dry-weight-basis water content". The values of water content for treated sludges were determined by the method presented in Appendix I of EM 1110-2-1906 (9) and in ASTM D2216-71 (10). Sludge samples of known weight were oven-dried at 60°C to constant weight. The weight loss upon drying was attributed to loss of interstitial water.

The water content of samples of treated sludge are listed in Table 9. These data indicate that the relative amount of interstitial water available after treatment is greatly process-dependent. Sludge treated by Process B exhibited values of water content comparable to those of natural soils. Process A produced treated products with a wide range of properties, but mostly resembling concrete with low interstitial-water content. Process C final products, being plastic or rubber-like masses, had relatively high water content, but the conventional dry-weight-basis water content determination has little meaning for such materials. The water content of the sludge portion of the electroplating sludge (No. 200) treated by Processor D was unknown because the plastic coating on the sample prevented the escape of water from within the sludge mass, but its low density implies that it had a relatively high void ratio and lower water content.

Bulk and Dry Unit Density

The bulk weight of a sludge sample is defined as the ratio of total weight (solids and water) to total volume. Dry unit weight is defined as the ratio of oven-dried (60°C) weight to total volume. The standard procedures for both tests are found in Appendix II of EM 1110-2-1906 (10). Volumes were computed using linear measurements of a regularly shaped mass obtained by trimming or cutting.

The bulk unit weight and oven dry unit weights of the treated sludges are presented in Table 9. Process B and C yielded materials whose bulk weight values were in the range of soils and whose bulk weight and dry unit weight values differed, as would those of soils. Process A resulted in materials having small differences between bulk weight and dry unit weight. These small differences reflect the lower water content of these fixed sludges. The two values obtained for sludge No. 200 were identical because of plastic coating prevented water from escaping from within the sludge mass during drying.

TABLE 9. PHYSICAL PROPERTIES OF TREATED SLUDGES

Sludge Number	Water Content %	Bulk* Unit Weight (kg/m^3)	Dry Unit Weight (kg/m^3)	Void Ratio	Porosity %
Process A					
200A	29.7	1610	1240	1.008	50.2
300A	20.6	1670	1380	0.963	49.0
800A	15.8	1650	1420	0.881	46.8
900A	20.9	1380	1070	1.418	58.7
Process B					
200B	83.6	1400	760	2.595	72.2
300B	97.2	1495	760	3.857	79.4
800B	30.3	1700	1304	1.181	54.1
900B	63.3	1380	850	2.225	69.0
Process C					
200C	43.2	1210	845	1.097	52.3
700C	45.6	1050	725	1.409	58.5
Process D					
200D	**	1180	1180	**	**

Note: Tests conducted using 60°C oven for drying. All values represent average of three samples.

* Sample air-dried prior to determination of unit weight.

** The water content, void ratio and porosity of sample 200D could not be determined because the sample was sealed in plastic.

Porosity and Void Ratio

The void ratio of a sludge sample is defined as the ratio of the volume of voids to the volume of solids and is normally expressed as a fraction. Porosity is defined as the ratio of the volume of void to the total volume and is expressed as a percentage. Standard test procedures for determining these parameters is found in Appendix II of EM 1110-2-1906 (9).

The values of void ratio and porosity of the treated sludges is also presented in Table 9. Processes A and C produced treated materials whose void ratio varied between 0.88 and 1.42 which corresponds with porosities of between 37 and 50 percent. These values are comparable to values expected from fine sands, silts, and silty clays. Process B treated materials showed higher values more in the range of values for soils with increasing amounts of clay particles. No determinations were made from the materials produced

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by Process D as its impervious plastic jacket precluded valid tests.

Atterberg Limits

Atterberg limit tests were performed on samples of treated and untreated IW sludges to determine the plasticity of the materials. The tests were designed to determine the limiting water contents (plastic limit (PL) and liquid limit (LL)) at which the material exhibits plastic and liquid behavior. Plasticity index (PI), or range of water contents at which the samples exhibit plastic behavior, is defined as a difference between LL and PL and is normally expressed as a percentage. Test procedures for determining the PL and LL are presented in Appendix III and IIIA of EM 1110-2-1906 (9) and ASTM Standard Test D424-59 and D423-66 (10). The PL is defined as the dry weight water content at which the sludge would start to crumble when rolled into a 1/8th-inch thread under the palm of the hand. The LL is defined as the lowest water content of which two halves of a soil specimen separated by a groove of standard dimension will close along a distance of one-half inch under the impact of 25 blows of the standard device.

The Atterberg limits of the five untreated IW sludges and the four sludges treated by Process B were determined. Values for LL, PL, and PI are listed in Table 10. Treatment Process B increased the LL and PI values of the sludge in some cases and decreased them in others. Evaluation of the data indicates a general decrease in plasticity due to this treatment process.

ENGINEERING PROPERTIES TESTS AND RESULTS

Compaction Test

A 15-blow compaction test was performed on treated sludge samples to determine the optimum water content for compaction and the unit weights which would be expected from field compaction of the treated sludge in a landfill. The test procedure is given in Appendix IV of EM 1110-2-1906 (9) and is identical with procedure of ASTM D698-70 (10) except that only 15 blows were used to compact each layer. A standard mold was filled as prescribed with three layers of treated sludge, each of which was compacted with 15 uniformly distributed blows using a 2.27 kg hammer with a 30.5 cm draw. Following compaction, the dry unit weight and dry weight basis water content were measured. The total process was repeated using different water contents until the water content at maximum compaction was determined. The test as described, simulates the compactive effort available when the sludges are placed in a landfill using typically available compacting equipment such as bulldozers. The total compactive effort of this test procedure is equivalent to 3.5×10^6 N-m/m^3.

Only sludges stabilized by Process B were amenable to this testing procedure. Values found for dry unit weight and optimum water content for these sludges are shown in Table 11. Optimum water content ranged from 37 to 73 percent for sludges treated by Process B. These values are well above those of typical soils.

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TABLE 10. ATTERBERG LIMITS OF UNTREATED SLUDGES AND THOSE TREATED BY PROCESS B

Sludge	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)
Untreated Sludges			
200R	107	58	49
300R	50	37	13
700R	201	109	92
800R	37	30	7
900R	NP*	NP	NP
Process B Treated Sludges			
200B	98	76	22
300B	NP	NP	NP
800B	38	33	5
900B	51	47	4

* NP = non-plastic

TABLE 11. CHANGES IN DRY UNIT WEIGHT AFTER COMPACTION AT OPTIMUM WATER CONTENT OF SLUDGES TREATED BY PROCESS B

Sludge Number	Dry Unit Weight (60° oven) Without Compaction (Kg/m^3)	Maximum After Compaction* (Kg/m^3)	Due to Compaction (Kg/m^3)	Optimum Water Content %
200B	760	810	+50	73
300B	760	1225	+465	46
800B	1310	1195	-115	37
900B	850	965	+115	51

* 15-blow compaction test (3.5×10^6 N-m/m^3 compactive effort).

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Unconfined Compression Test

The unconfined compression test was used to determine the uniaxial, unconfined compressive strength of cohesive or cemented materials. A cylindrical specimen of treated sludge was prepared and loaded axially until failure. The peak compressive stress sustained by the material was considered the unconfined compressive strength of the material. The modulus of elasticity was determined from composite stress-strain diagrams constructed from the multiple compression test. The procedures used followed Appendix XII of EM 1110-2-1906 (9) and ASTM Standard Method D 2166-66 (10) except that a specimen height-to-diameter ratio of 2.0 was used instead of the prescribed 2.1 ratio.

The unconfined compressive strength varied significantly between the different treatment processes (Table 12). Process B produced material with

TABLE 12. SUMMARY OF UNCONFINED COMPRESSION TESTS FOR TREATED INDUSTRIAL WASTE SLUDGES

Sludge and Process	Initial Dry Unit Weight (Kg/m^3)	Unconfined Compressive Strength (N/cm^2)	Youngs Modulus of Elasticity (N/cm^2)
Process A			
200A	1250	53	1.00×10^4
300A	1400	117	1.76×10^4
800A	1435	92	1.59×10^4
900A	1150	18	1.61×10^3
Process B			
200B	980	22	1.09×10^3
300B	1210	5.5	2.49×10^2
800B	1360	15	8.48×10^2
900B	1010	17	8.00×10^2
Process C			
200C	855	515	5.31×10^4
700C	730	210	2.39×10^4
Process D			
200D	1120	1065	1.32×10^5

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unconfined compressive strengths between 5.5 and 22 N/cm^2 which is in the same range as cohesive or cemented soils. Process A produced material more typical of low-strength, soil-cement mixtures (18 to 117 N/cm^2). Process C treated products had higher strength nearing that of low-strength concrete (200 to 500 N/cm^2). The high value of unconfined compressive strengths found for plastic encapsulated sample (No. 200D) is indicative only of samples with the same configuration (i.e., cyclinders 6.7 cm in diameter by 10.2 cm high) due to its composite structure.

The ratio of stress to strain, Young's Modulous of elasticity are also presented in Table 12. Sludges treated by Process B showed moduli of elasticity about two orders of magnitude less than other treated materials as would be expected for a low strength, soil-like material. Other treated products had elasticity values similar to those of low-strength concrete.

Permeability Tests

The permeability of the treated and untreated sludges were determined by two, common falling-head permeability-tests--the untreated sludges were tested using an open vessel with a 20 cm head while the treated sludges were tested in a triaxial compression chamber with back pressure of 6.9 N/cm to insure complete saturation. These two testing procedures have been extensively described in an earlier report (8).

The untreated sludges had very low permeabilities (from 3×10^{-5} to 6.5×10^{-6} cm/sec) as might be expected from their very fine grain texture. A summary of the falling head permeability test for these sludges is shown in Table 13. The chlorine production brine (No. 800) had the highest percent solids and dry unit weight, the lowest void ratio and one of the highest permeabilities. The permeabilities of the other IW sludges were generally less than about 1×10^{-6} cm/sec. This permeability is equivalent to water movement of only about 0.5 cm per week. These tests were run on newly poured sludges which had been giving only enough settling time to give short-time constant permeability results. The sludges would be expected to densify to a greater (and unknown) extent with a concommitant further decrease in permeability as is indicated by the efforts of short-term vibrating given in the second set of data in Table 13.

The results of permeability tests on the treated sludge samples are given in Table 14. All treatments greatly increased the solids and dry unit weight of the sludges, producing a denser solid with lower water content and void ratio as might be expected. However, Processes A and B produced no consistent change of permeability from that of the untreated sludge. Each reduced the permeability of two of the sludges of one treatment (not the same in all cases), but increased, or did not affect, the permeability of the other two sludges. Process C increased the permeability of both treated sludges by over two orders of magnitude, the treated sludges having permeability more than 100 times those of the untreated sludges.

Results of laboratory determinations of permeability measured on treated sludge samples are only valid under field conditions where the

TABLE 13. SUMMARY OF FALLING-HEAD PERMEABILITY TEST DATA FOR UNTREATED INDUSTRIAL WASTE SLUDGES

Sludge Number	Percent Solids (%)	Water Content* (%)	Dry Unit Weight (Kg/m^3)	Void ratio	Coefficient of Permeability** (cm/sec)
200R	33	194	455	4.9	3.1×10^{-6}
	39	153	510	4.3	1.2×10^{-6}
300R	43	132	710	4.6	5.7×10^{-6}
	46	116	890	3.5	1.3×10^{-6}
700R	36	171	450	5.9	$6.5 \times 10-^{6}$
	45	119	545	4.7	3.3×10^{-6}
800R	60	66	1035	1.7	(No data)
	62	61	1185	1.4	8.1×10^{-5}
900R	43	128	760	2.6	3.5×10^{-5}
	50	98	860	2.2	2.8×10^{-5}

Note: All drying done in 60°C oven. Two sets of data for each sludge--samples were tested after settling then vibrated (densified) and retested (lower values).

* Dry weight basis.

** Corrected for water at 20°C.

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TABLE 14. SUMMARY OF FALLING-HEAD PERMEABILITY TEST DATA FOR TREATED INDUSTRIAL WASTE SLUDGES

Sludge Number	Percent Solids (%)	Water Content* (%)	Dry Unit Weight (Kg/m^3)	Void ratio	Coefficient of Permeability** (cm/sec)
Process A					
200A	71.4	40.6	1185	1.12	4.0×10^{-7}
300A	82.0	22.4	1365	1.01	1.9×10^{-6}
800A	77.0	30.2	1335	1.02	8.5×10^{-7}
900A	83.0	19.5	1100	1.37	3.8×10^{-5}
Process B					
200B	64.6	55.6	855	2.21	1.1×10^{-5}
300B	69.5	43.7	1190	2.12	2.0×10^{-4}
800B	71.4	39.9	1155	1.48	3.6×10^{-5}
900B	66.7	49.8	995	1.77	8.7×10^{-6}
Process C					
200C	65.7	52.1	620	1.88	1.1×10^{-4}
700C	60.6	64.7	590	1.93	1.6×10^{-4}

Note: All drying done in 60°C oven.
* Dry weight basis.
** Corrected for water at 20°C.

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treated materials have not cracked or disintegrated and are fully saturated with leaching media. Cracking or spalling greatly increases the permeability of the sample as well as the surface area exposed. Complete saturation of the solidified sludges requires an extremely large hydrostatic pressure (head) or a very long time and may never be completed under actual field conditions. Incomplete saturation lowers the effected permeability of the sample so that, in this regard, the values given are "worst case" as far as saturation is concerned.

Durability Tests

The long-term physical stability of these solidified sludges was evaluated using two standard ASTM tests commonly used to estimate the durability of soil cement mixtures--the freeze-thaw and the wet-dry testing procedures. Although treated sludges disposed of properly in landfills are placed above the water table and below the frost line, these are thought to be reliable tests of the overall durability of the treated sludge samples even though they may represent "worst case" or unusual situations.

Freeze-Thaw Test

Properly cured solidified sludge samples were subjected to the standard freezing and thawing tests of compacted soil-cement mixtures, ASTM test D560-57 (10). This test consists of 12 test cycles of 24 hours freezing of a standard cylindrical sample, followed by thawing for 23 hours and two firm strokes on all surfaces with a wire scratch brush. Performance is evaluated by determining the weight loss after 12 cycles, or the number of cycles to disintegration, which ever occurs first.

Of the samples tested only one, the plastic encapsulated sample of sludge No. 200 by Process D, survived the 12 test cycles. All other tested samples disintegrated before 12 test cycles were completed, 62 percent after only two test cycles. Evidently none of the processes used in this study were designed to withstand freezing conditions on the assumption that such circumstances might never be encountered if the treated wastes are disposed of properly.

Wet-Dry Test

A much less severe durability test which is similar to the freeze-thaw test is the standard ASTM wet-dry test as detailed in ASTM D 559-57 (10). This is the standard wetting and drying test for soil-cement mixtures. Cured cylinders of treated sludges are again subjected to 12 test cycles, each consisting of 5 hours submergence in water, 42 hours of oven drying (60°C) and two firm strokes on all surfaces with a wire scratch brush. Again test results are presented as weight loss after 12 complete cycles, or the number of cycles to disintegration, whichever occurs first.

Sludge treatment did not produce a product capable of undergoing 12 freeze-thaw or wet-dry cycles. Indeed, over half of all specimens treated

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disintegrated after one or two cycles and except for the plastic encapsulated samples of the electroplating sludge (No. 200D), no sample tested held up over 9 full cycles, 70 percent disintegrating on the second cycle. Process A produced samples with the greatest durability. Process B, which produced a soil-like product, disintegrated consistently after only one or two cycles; but its products were not representative of durable solids. Both solidified sludges (No. 200 and No. 700) treated by Process C were unusual in that they both survived nearly 12 cycles of freeze-thaw tests but disintegrated after only one wet-dry cycle, which is considered to be the milder test.

SUMMARY OF PHYSICAL AND ENGINEERING PROPERTIES TESTS

The industrial waste sludges selected for this study are typical of the wide array of waste streams common in many manufacturing processes. Their solids content averages around 50 percent solids. Further dewatering is difficult and expensive since their median grain size averages about 25 microns and their specific gravities range from 2.70 to 3.96; the sludges consist of small, heavy, hydrophilic particles which settle only slowly and are easily resuspended. Another important aspect of this composition is the low permeabilities of the raw sludges even after short-term settling. Further decreases in permeability of the undisturbed sludge upon standing would be expected since even brief densification by vibration decreased the permeability of all the sludges by an average of 50 percent, and also decreased the void ratio and water content. These sludges have poor handling characteristics since they are largely liquid in nature and even after extensive settling or dewatering remain thixotrophic and unable to carry loads.

The solidification/stabilization processes which treated the IW sludges all produced distinct types of products: Process A produced a solid, monolithic mass which resembled slow-strength concrete; Process B, a soil like product which remained soft and friable and had a soil-like consistency; Process C, a rubber-like solid; and Process D, a solid, plastic-coated product which had properties quite different from the other treatment systems. Sludges fixed by Process B, because of the soil-like nature, were ameniable to several of the tests made on the untreated sludges such as grain size analysis, Atterberg limits, changes in dry unit weight due to compaction, and optimum water content.

Process B had little effect on the median grain size after disaggregation--two of the sludges (No. 200 and No. 800) had identical median grain sizes while two had slightly increased median grain sizes (No. 300 and No. 900) after treatment. No consistent changes in the liquid or plastic limits of the plastic index were noted which could be related to the treatment process. The optimum water content of wastes treated by Process B as determined by the compaction tests were generally higher or equal to values commonly recorded for typical soils.

The specific gravity of the IW sludges was not changed materially by either Process A or Process B--the treated sludges had a range of specific gravities of 2.49 to 3.68 compared to 2.70 to 3.96 for the untreated sludge.

The urea-formaldehyde treatment process (C) produced solids with specific gravities of 1.74 and 1.77 for the two sludges treated--a little over half of that of comparable untreated sludges. Process D, which encapsulated the solidified and dried sludge No. 200, produced a product with a specific gravity near that of water (1.18)--by far the lowest of any treatment technique. The contained dry sludge must have a high void ratio to have such a low specific gravity.

Physical properties of the treated sludges produced by Process B were typical of a soil or soil-cement mixture. They had a high water content, and high void ratio and porosity. Sludges treated by Process A exhibited the lowest water content and void ratios and porosities as might be expected of low-strength concrete. Two sludges treated by Process C were intermediate in properties.

This same pattern is found in the results of the engineering properties testing. Process B products have unconfined compressive strengths averaging 14.8 N/cm^2 while the average for Process A products is 70 N/cm^2. Products produced by Process B also have moduli of elasticity one to two orders of magnitude less than all other treated sludge. The permeability of the IW sludges are generally increased by treatment by Process A but are generally decreased by treatment by Processes B and C.

All treated sludges (except the plastic-coated samples) were susceptable to freeze-thaw and wet-dry damage--very few staying intact through more than 1 or 2 cycles. An exception was those sludges treated by Process C which, although susceptible to wet-dry cycles, withstood up to 14 freeze-thaw cycles without damage. The lack of durability might not be surprising since these processes were developed primarily to protect the contents from loss to leaching waters at the lowest possible cost of materials. No physical property parameters were set forth in the original proposals to the vendors in this study other than that the products were to be typical of those disposed of in landfills.

No consistent changes in physical and engineering properties were found between the treated products which could necessarily be correlated to the containment efficiency. The four processes in this study produced products with very different properties. Perhaps physical properties test designed specifically for each type of treatment process might better distinguish between the important aspects of the physical properties.

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SECTION 6

RESULTS OF CHEMICAL ANALYSIS AND LEACHING TESTS

CHEMICAL ANALYSIS OF UNTREATED SLUDGES

Samples of the industrial waste sludges used in this study were dried in a 60°C oven, digested in 6N nitric acid and analyzed for major constituents of interest as shown in Table 15. The percent recoveries ranged from 30 percent to 114 percent. Lower recoveries must reflect high concentrations of those elements not included in the analysis list such as sodium (especially for sludge No. 300), potassium, fluoride (sludge No. 900), phosphate and carbonate, and the possible presence of organic constituents. Although the sludges represent a wide array of industrial process wastes, all are high in a variety of heavy metals and/or anions which have a high potential for polluting soils and water supplies if not correctly handled.

The constituents generally present in the sludges at the highest concentrations are calcium, chloride, sulfate and silicon. Sludges 200, 700, and 800 contain 60 to 85 percent of these constituents; while sludges 300 and 900 contain only 14 and 29 percent of these constituents, respectively.

The concentration of heavy metals in the sludges varies widely from over 25 percent of the total material to less than 0.5 percent. Some contain very high levels of known toxic metals. The electroplating sludge (No. 200) contains several heavy metals at potentially dangerous levels: chromium, 7.6 percent; copper, 4.5 percent; zinc, 0.75 percent; and nickel, 0.30 percent. The Ni-Cad battery sludge (No. 300) contains almost 17 percent nickel, 0.6 percent iron, and 0.46 percent cadmium. The pigment production sludge (No. 700) contains over 11 percent lead, 8 percent chromium, 6 percent iron, over 0.60 percent copper and cadmium, and 0.33 percent zinc. The chlorine-production brine (No. 800) and the glass etching sludge (No. 900) have only minor amounts of heavy metals. Only iron is present at concentrations over 1 g/kg. These represent sludges having potential pollution problems related to the production of leachates with high ionic strength.

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TABLE 15. ANALYSIS OF SELECTED DRY SLUDGE SOLIDS OF INDUSTRIAL WASTES IN THIS STUDY

Constituent	Electroplating Sludge (200)	Ni-Cad Battery Sludge (300)	Pigment Production Sludge (700)	Chlorine Production Brine (800)	Glass Etching Sludge (900)
As	19.5*	BDL**	170	17.0	19.0
Be	305	12.9	BDL	BDL	BDL
Ca	125,500	24,200	19,000	282,000	30,900
Cd	710	4,647	6,350	6.4	4.8
Cr	75,800	151	86,500	10.0	94.0
Cu	45,850	322	6,950	313	498
Fe	12,050	6,260	68,500	4,670	6,450
Hg	1.0	4.5	57	125	2.6
Mg	7,285	1,070	27,300	2,900	9,950
Mn	215	170	2,590	115	264
Ni	3,050	168,900	1,410	153	708
Pb	878	102	114,000	81.0	330
Zn	7,570	1,439	3,280	217	580
Cl	220,000	119,900	490,000	160,000	160,000
SO	270,000	10,000	160,000	53,500	37,500
Si^4	57.0	19,390	167,000	10,900	61,600
% recovery	76	34	114	51	30

* All values are mg/kg in dry sludge solids.

** BDL = below detection limits.

LEACHING TESTS RESULTS

General Patterns of Constituent Loss from Leaching Columns

The small-column leaching test was designed to simulate conditions which might occur in the landfill disposal of treated and untreated industrial waste sludges. It was assumed in the initial planning of the testing procedures and leachate collection schedule that the concentrations of constituents in column leachates would be high initially after which they would fall rapidly in a logarithmic pattern (11). As discussed in a previous report (2), three basic patterns of constituent loss were observed in the flue gas cleaning sludge study. Two of these same patterns were evident in this project.

The first pattern is produced by those constituents exhibiting the predicted high-early-loss-rate followed by an asymtotic drop to some low constant value (often at or near zero). These constituents typically are those which have high solubilities in the leaching medium compared to their concentrations in the waste sludges. This pattern was typical for anions in leachates from treated and untreated sludges alike. Examples of this pattern are shown for chloride and sulfate in Figure 12. Chloride is extremely high in concentration in the early leachate samples (over 24 g/l) but rapidly falls to near zero concentrations (averaging about 0.035 g/l) from the 14th day to end of the experiment (814 days later). Evidently nearly all of the leachable chloride is removed from the column at an extremely rapid rate. Sulfate levels are nearly as high as chloride in the first two sampling periods, but also rapidly fall off. However, in this case the sulfate concentration falls not to zero but to the solubility of calcium sulfate in the leaching median (average of about 1.5 g/l SO_4) for the duration of the leaching period. Evidently the soluble sulfate salts are rapidly lost from the columns. Although the actual amounts may vary, this pattern is typical of that found for these anions for all columns whether treated or not. Similar leaching patterns would likely be found for the univalent cations (such as sodium and potassium) which must be accompanying these high early anion losses. Some soluble cations may also be leached from the samples with this pattern.

The second leaching pattern, which is exhibted by calcium in Figure 12, is typical of constituents present in the sludge at levels well above their solubility in the leaching median. The level of calcium in the leaching median is very consistent, averaging near 0.6 g/l--near to that which would be predicted from the solubility of calcium sulfate at the observed pH's. Calcium sulfate must represent the major leaching species for both constituents over the duration of the experiment. After 814 days of leaching this sludge, the calcium concentration remains near 0.6 g/l and sulfate at 1.6 g/l--representing their maximum solubility in the leaching medium.

The pattern of leaching of most polyvalent cations falls between the two patterns just described. Often the first few leachate samples have higher metal concentrations, possibly reflected the higher solubilities of the metal chlorides in the high chloride leachates. As the leachate

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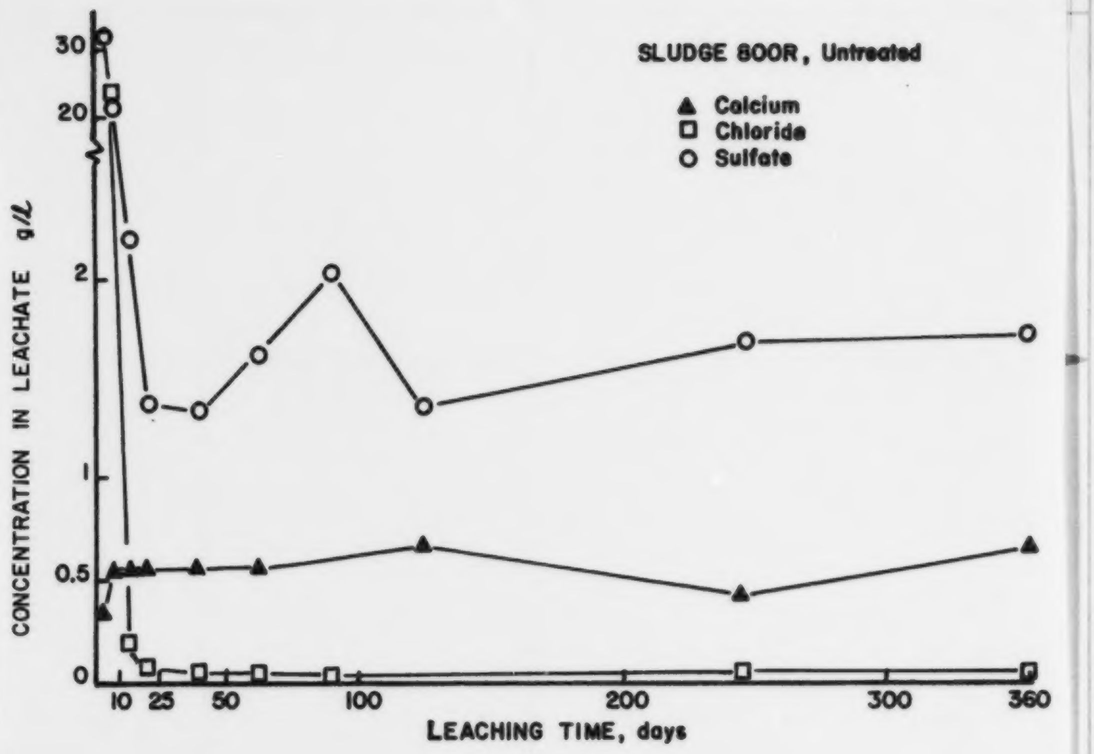

Figure 12. Leaching pattern plot.

concentrations begin to stabilize, the levels of metals decrease to a low, consistent value similar to that exhibited by sulfate, but usually at lower levels. The relative levels of the initial concentration peak and the later stabilized leaching rate can be estimated from the highest and overall concentrations for the various constituents for all priority columns listed in the tables in the next section.

The third leaching pattern observe only in the previous study with flue gas cleaning wastes consists of low initial constituent concentrations followed at some later time by increasing leach rates. This pattern is usually due to changes in flow patterns, in or break-down of, the sludge (2).

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Examples of this pattern are not found in this study although individual samples show increasing levels of many heavy metals because the leachate from all columns generally became 1.5 to 2 pH units more acidic as the experiment progressed. As the pH of the leachate shifts to more acid conditions, the solubility of the major heavy-metal salts increases, and their rate of loss accelerates.

Leaching Rates, Column Loading and Data Interpretation

Interpretation of the leaching data is complicated by the variations in the column loading of dry sludge solids and by the low and variable leachate production rates from several of the control (untreated) sludge columns. The amount of dry sludge solids loaded into the columns (Table 3) varied among the different columns containing treated and untreated sludges so that different quantities of the sludge constituents were available for leaching from the different columns. For instance, the amount of dry sludge solids loaded into the untreated sludge columns varied between about 4.5 kg for sludge No. 200 to over 9.5 kg for sludge No. 800. This was largely due to the different amounts of moisture present in the sludge since fairly uniform amounts of wet sludge (11.7 to 15.4 kg) were loaded into these columns.

A greater discrepancy occurred between the amount of sludge loaded into the untreated (control) sludge columns and the treated sludge columns. Smaller amounts of dry sludge solids were loaded into all treated sludge columns due both to the dilution of the sludges by the treatment additives and to the smaller space occupied in the column by the treated sludge cylinders because of the outer bead-layer. For sludge No. 200, the untreated sludge had 4.5 kg of dry sludge solids while Process A-treated columns only contained 1.85 kg (41 percent); Process B, 2.37 kg (52 percent); Process C, 1.57 kg (35 percent); Process D, 1.25 kg (28 percent) of dry sludge solids--nearly a four-fold difference. For sludge No. 300 the untreated sludge column contained 6.15 kg dry sludge solids, while Process A No. 300 column contained 1.78 kg (29 percent) and Process B No. 300 column had 3.26 kg (53 percent) dry sludge solids. Sludge No. 700 was only treated by Process C which loaded 30 percent (1.44 kg) of the amount of dry sludge solids in the untreated columns. For sludge No. 800, the columns containing sludge treated by Processes A and B had 36 percent and 54 percent of the dry sludge solids contained in the control (untreated) sludge columns. Similarly sludge No. 900 treated by Process A loaded 40 percent of the 6.57 kg of dry sludge solids loaded into the untreated sludge No. 900 column.

The low leachate flow rates from all untreated sludge columns (except for No. 800 sludge column) is believed to be caused by the low permeability of the settled sludges (see Table 13). The average flow rates from priority columns containing untreated sludges 200, 300, 700 and 900 range from 11 to 17 ml per day (Table 16). These low flow rates resulted in the production of too little leachate to perform all analysis which were planned at each sampling time. Thus, data for the untreated sludge columns was often incomplete, so that comparisons with the data derived from treated sludge columns were frequently difficult. The flow of leachate through the treated sludge

TABLE 16. VOLUMES OF LEACHATE COLLECTED FROM PRIORITY COLUMNS AND THE CALCULATED VOLUME OF LEACHATE PER DAY

Sampling Day	Collecting Interval (Days)	Sludge No. 200		Sludge No. 300		Sludge No. 700		Sludge No. 800		Sludge No. 900	
		Vol (1)	Flow Rate (1/Day)	Vol (1)	Flow Rate (1/Day)	Vol (1)	Flow Rate (1/Day)	Vol (1)	Flow Rate (1/Day)	Vol (1)	Flow Rate (1/Day)
1	1	0.14	0.14	0.36	0.36	0.14	0.14	0.92	0.92	0.28	0.28
8	7	0.26	0.037	0.26	0.037	0.29	0.041	4.5	0.643	0.26	0.037
14	6	0.29	0.048	0.35	0.058	0.19	0.032	3.70	0.617	0.33	0.055
21	7	0.22	0.031	0.30	0.043	0.14	0.020	4.06	0.580	0.26	0.037
28	7	0.21	0.030	0.22	0.031	0.14	0.020	3.25	0.464	0.22	0.020
39	11	0.22	0.020	0.10	0.009	0.10	0.009	1.70	0.154	0.14	0.013
63	24	0.16	0.007	0.19	0.008	0.09	0.004	3.10	0.129	0.21	0.009
91	28	0.64	0.023	1.00	0.036	0.43	0.015	4.5	0.161	0.93	0.033
126	35	0.24	0.007	1.34	0.038	0.57	0.016	4.01	0.114	1.26	0.036
189	63	ND	--	2.55	0.044	ND	--	ND	--	1.69	0.027
245	56	2.98	0.053	ND	--	3.02	0.054	3.56	0.063	ND	--
353	108	1.69	0.016	ND	--	1.69	0.016	3.06	0.028	1.69	0.016
451	98	ND	--	ND	--	1.69	0.017	1.89	0.029	ND	--
569	118	ND	--	ND	--	1.40	0.012	1.36	0.011	1.51	0.013
708	139	1.85	0.013	2.03	0.015	1.86	0.013	2.03	0.015	1.69	0.012
814	106	ND	--	1.69	0.016	2.12	0.020	1.86	0.017	ND	--
Total	814	8.90	0.011	10.38	0.013	13.83	0.017	44.50	0.054	10.45	0.013

NOTE: Samples collected until 4.51 had accumulated at which time flow was stopped. ND = not determined or no flow.

columns was uniformly high due to the highly permeable external layer of polypropylene beads (Fig. 6).

The leaching data are presented in three different ways which address different aspects of the potential for the sludges to lose pollutants to the environment. The "overall" leachate concentration summary presents the concentration of the constituent under consideration as if all of the leachate were pooled and analyzed at one time. These data give the average leachate concentration over the duration of the experiment. A second view of the data is presented by listing the "highest" concentration of the constituent found in any single leachate sample throughout the entire experiment. This number represents the "worst case" value and gives an estimate of maximum concentration of the parameter which might be found in any leachate sample. As this number represents a single value, a wide variation can be expected. Comparison of the "overall" and "highest" values for any parameter give a rough idea of the variability of the concentrations found throughout the experiment--small differences between these two numbers indicate uniform and consistent concentration while a large number is indicative of a larger concentration variability.

The "overall" and "highest" values are presented for all columns containing the same type sludge in the same table to facilitate comparisons between the values for different treatments and the untreated sludge columns. A comparison of the leach rates of the various parameters from those columns containing sludges processed by different processors with the leachate from the corresponding untreated sludge columns is also presented. The comparison is presented in two ways--a simple "H" or "L" if the treated sludge column leachate value is higher or lower than the untreated sludge (control) column leachate, and a T/U ratio which is the concentration of the particular constituent in the leachate from the treated sludge column divided by the concentration of the parameter in the leachate from the untreated sludge (control) column containing the same sludge type. The T/U ratio gives a quantitative measure of the "H" and "L" relationship in the Table.

A third presentation, the percent of each constituent leached from the column, is calculated by accumulating the mass (concentration in mg/l × the volume leached in liters) of each constituent present in the leachate over the total experiment. These masses are presented as the percentage of the amount of that constituent present in the dry sludge solids actually loaded into each column. (The total mass of each constituent leached and loaded into each column is given in Appendix B). Any materials which might have been added during processing are not included in this calculation of constituents loaded into the column so that losses of over 100 percent are possible. This calculation is included because it takes into account the wide variation in column sludge loading between the "control" and treated sludge columns. Most treated sludge columns contain half or less the dry sludge solids of their respective untreated controlled columns. These percent-leached figures are further compared for treated and untreated sludge columns in an approach similar to that described above for the "overall" and "highest" values using the higher and lower designation and the treated to untreated (T/U) ratio.

Electroplating Waste Sludge (No. 200) Leach Testing Results

Leachate from the untreated electroplating waste contained five constituents which had overall concentrations greater than current drinking water standards (Table 17). Cadmium, copper, manganese, and lead had average concentrations one to three times drinking water standards, while sulfate levels in the leachate averaged over 36 times higher. Calcium, magnesium, and chloride, while not at unacceptable levels, were in the problem range of between 100 and 1000 mg/l. Nine constituents had highest concentrations above the standards. Cadmium, manganese, lead, selenium, and sulfate were found at least once at concentrations over ten times, and up to 76 times the drinking water standards. Arsenic, copper, and chloride had highest concentrations 1.5 to 4 times higher than the standards. Calcium and magnesium also have high levels of over 500 and 1000 mg/l, respectively. Of the six constituents present in the dry sludge solids at over 30,000 mg/l, only zinc was not found at problem levels.

The loss of constituents from the untreated electroplating waste presents a serious problem to surrounding soils and waters. Besides the heavy metal loss rates cited above, the very high loss rates of magnesium and sulfate should be stopped by any successful waste treatment system. Even though magnesium is present in lower quantities than calcium in the dry sludge solids, the leachates of the untreated sludge contained nearly twice the overall and average concentrations of magnesium than calcium. These high magnesium levels must reflect the relatively greater solubility of magnesium sulfate. This increased solubility is also reflected in the much greater percent (13.5 percent) of magnesium which was lost from the column in the leaching medium.

The concentrations of selected constituents leached from the priority columns containing electroplating waste treated by Processes A through D are also presented in Table 17. To aid in comparison of the composition of leachate from the treated columns with those from the untreated sludge (control) column, these values are compared for the overall constituent concentrations in Table 18 and for the highest concentrations found in Table 19. Both tables present a single H or L if the leachate levels from the treated sludge columns were higher or lower, respectively, than the untreated sludge (control) column. The ratio of the actual concentration values found in leachate from the treated and untreated sludge columns, labeled T/U ratio, indicates the factor by which the leachate from the treated sludge column is higher or lower than the untreated control.

Of the four treatment systems which processed the electroplating sludge, process D produced leachate which was consistently lower in all constituents than leachate from the control columns. The higher cadmium levels reflect a single high sample, 10 of 11 samples being below detection limits of less than one thousandth of that single high value. Process D

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TABLE 17. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM TREATED AND UNTREATED, PRIORITY COLUMNS CONTAINING ELECTROPLATING WASTES (NO. 200)

Constituent	Untreated Sludge* Column		Process A Column		Process B Column		Process C Column		Process D Column	
	Overall**	Highest	Overall	Highest	Overall	Highest	Overall	Highest	Overall	Highest
As	0.016	0.077	0.003	0.007	ID†	0.004	0.001	0.010	.001	.010
Be	0.004	0.010	0.001	0.003	ID	0.004	1.830	4.44	ID	0.0004
Ca	288	519	555	1210	232	660	395	689	2.42	15.0
Cd	0.019	0.110	0.013	0.079	ID	0.0017	7.98	20.9	0.169	2.24
Cr	0.043	0.095	0.038	2.50	4.53	24.80	46.0	300	0.001	0.005
Cu	1.175	3.700	0.703	3.60	2.38	13.60	295	800	.015	0.038
Hg	0.003	0.014	ID	0.0006	ID	0.0032	0.001	0.004	<0.0001	0.0007
Mg	507	1035	3.54	9.70	0.034	0.200	185	570	0.005	0.100
Mn	0.155	0.790	0.063	0.922	0.002	0.020	1.85	6.30	0.001	0.005
Ni	0.284	2.50	0.017	0.083	0.038	0.168	33.8	123	0.001	0.015
Pb	0.057	0.975	0.009	0.034	0.038	0.384	0.095	0.700	0.049	0.400
Se	ID	0.646	ID	0.168	ID	0.041	ID	ID	ID	ID
Zn	0.073	0.570	0.011	0.010	0.008	0.070	92.2	368	0.003	0.014
Cl	140	1066	6.150	26.0	109	495	19.9	60.0	2.20	15.0
SO_4	9220	18900	12.4	3000	3040	14500	4305	13800	214	450
COD	ID	BDL	ID	ID	ID	ID	ID	7010	ID	127
TOC	ID	BDL	ID	ID	ID	ID	ID	2800	ID	6

* In mg/l.

** Overall is total mg leached/total 1 leachate collected; highest is highest concentration found in any individual sample.

† ID = insufficient or missing data.

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TABLE 18. COMPARISON OF OVERALL CONCENTRATIONS OF SELECTED CONSTITUENTS LEACHED FROM TREATED, ELECTROPLATING SLUDGE (NO. 200), PRIORITY COLUMNS WITH THOSE LEACHED FROM UNTREATED CONTROL COLUMNS

	Process A Column		Process B Column		Process C Column		Process D Column	
Constituent	High or Low	T/U*	High or Low	T/U	High or Low	T/U	High or Low	T/U
As	L**	0.19	ID†		L	0.06	L	0.06
Be	L	0.25	ID		H	460	ID	
Ca	H	1.9	L	0.80	H	1.4	L	0.008
Cd	L	0.68	ID		H	4200	L	8.9
Cr	L	0.88	H	105	H	1070	L	0.023
Cu	L	0.60	H	2.0	H	250	L	0.013
Hg	ID		ID		L	0.30	L	0.03
Mg	L	0.007	ID		L	0.36	L	10^{-5}
Mn	L	0.41	L	0.013	H	12	L	0.006
Ni	L	0.06	L	0.13	H	120	L	0.003
Pb	L	0.16	L	0.67	H	1.7	L	0.86
Zn	L	0.15	L	0.11	H	1260	L	0.041
Cl	L	0.044	L	0.78	L	0.14	L	0.016
SO_4	L	0.001	L	0.33	L	0.47	L	0.023

* T/U = overall concentration of constituent in leachate from treated sludge divided by overall concentration in leachate from untreated sludge column.

** H or L = overall concentration of constituent leached from treated sludge column higher or lower than that from untreated sludge column.

† ID = insufficient or no data.

TABLE 19. COMPARISON OF HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS LEACHED FROM TREATED, ELECTROPLATING SLUDGE (NO. 200), PRIORITY COLUMNS WITH THOSE LEACHED FROM UNTREATED CONTROL COLUMNS

	Process A Column		Process B Column		Process C Column		Process D Column	
Constituent	High or Low	T/U*	High or Low	T/U	High or Low	T/U	High or Low	T/U
As	L**	0.091	L	0.052	L	0.130	L	0.13
Be	L	0.30	L	0.40	H	440.	L	0.040
Ca	H	2.3	H	1.27	H	1.3	L	0.028
Cd	L	0.72	L	0.015	H	190	H	20
Cr	H	26	H	260	H	3160.	L	0.050
Cu	L	0.97	H	3.6	H	220.	L	0.010
Hg	H	0.043	L	0.23	L	0.28	L	0.50
Mg	L	0.009	L	0.0002	L	0.55	L	0.0001
Mn	H	1.2	L	0.025	H	7.9	L	0.006
Ni	L	0.033	L	0.067	H	49.	L	0.006
Pb	L	0.035	L	0.39	L	0.72	L	0.41
Zn	L	0.017	L	0.12	H	645	L	0.024
Cl	L	0.024	L	0.46	L	0.056	L	0.014
SO_4	L	0.16	L	0.76	L	0.73	L	0.023

* T/U = highest concentration of constituent in leachate from treated sludge divided by highest concentration in leachate from untreated sludge column.

** H or L = highest concentration found in leachate samples from treated higher or lower than that from untreated sludge column.

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includes complete encapsulation of the solidified sludge in a 0.63 cm-thick, polyethylene jacket which effectively isolates the sludge from the leaching medium and as such successfully contained all constituents.

Processes A and B were both moderately successful in lowering the "overall" and "highest" concentrations of the various constituents for which the leachates were analyzed. Process A, which uses flyash and a lime additive to produce a pozzolan product which sets into a monolithic mass, reduced the overall concentration of all constituents except calcium. Eight of the constituents were found at average levels less than one-tenth the controls. Leachate from Process A had two constituents--calcium and chromium at concentrations higher than controls in at least one leachate sample. Chromium was much higher at 26 times the highest level in untreated control leachate. Calcium was present at about twice the highest levels of constituents analyzed in the controls.

Process B, which uses two additives to produce a soil-like final product was only slightly less effective than Process A. The average overall concentrations of two constituents (chromium and copper) and the highest concentrations found for three constituents (calcium, chromium, and copper) were higher than the levels in their respective controls. Chromium was present at very high levels--105 times the overall control levels and 260 times the highest level found in the control leachates.

Process C, which acidified the sludge during treatment to form a urea-formaldehyde resin containing the treated sludge did not effectively contain the majority of sludge constituents. Six constituents--beryllium, cadmium, chromium, copper, nickel and zinc--had overall concentrations in the leachate from treated columns greater than two orders-of-magnitude higher than the level in untreated (control) column leachate. Cadmium, chromium, and zinc had average concentration over 1000 times the controls. The highest concentrations found in any single leachate sample indicated the same pattern of high constituent loss with beryllium, cadmium, chromium, copper, and zinc having highest concentrations over 100 times the highest control leachate level.

The percent of each constituent leached from all priority electroplating waste columns is summarized in Table 20. Except for calcium, magnesium, and sulfate much less than 1 percent of constituents were lost from the control columns over the course of the experiment. The small percentage of the sludge materials lost would indicate that the loss of constituents could continue from these sludges at rates similar to those found in this study for many years. Magnesium was lost at high rates due to the high solubility of magnesium sulfate.

The calculation of the percent of each constituent leached from the treated sludge columns corrects for the smaller amount of dry sludge solids loaded into the treated sludge columns. This lessens the advantage afforded those processers who included large amounts of additives in the treatment process. The "overall" and "highest" concentration calculations above give an advantage to the processor who included the smallest amount of sludge in

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TABLE 20. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING TREATED AND UNTREATED ELECTROPLATING SLUDGE (NO. 200)

Constituent	Untreated Sludge % Leached*	Process A Treated % Leached	Process A Treated High or Low	Process A Treated T/U**	Process B Treated % Leached	Process B Treated High or Low	Process B Treated T/U	Process C Treated % Leached	Process C Treated High or Low	Process C Treated T/U	Process D Column % Leached	Process D Column High or Low	Process D Column T/U
As	0.16	2.7	H†	17.	0.019	L	0.12	0.005	L	0.03	0.270	H	1.69
Be	0.003	0.003	-	1.0	0.004	H	1.3	10.2	H	3400.	0.001	L	0.33
Ca	4.5	7.5	H	1.7	3.6	L	0.8	5.3	H	1.2	0.057	L	0.013
Cd	0.005	0.032	H	6.4	0.002	L	0.4	19.1	H	3800.	0.700	H	140.
Cr	<0.001	0.009	H	>9.	0.063	H	>63.	1.03	H	>1000.	<0.001	-	--
Cu	0.005	0.026	H	5.2	0.102	H	20.	10.9	H	2200.	0.001	-	0.2
Mg	13.7	0.83	L	0.006	0.009	L	0.0006	43.2	H	3.2	0.021	L	0.002
Mn	0.140	0.51	H	3.6	0.020	L	0.14	14.6	H	104.	0.014	L	0.100
Ni	0.018	0.010	L	0.55	0.025	H	1.4	18.8	H	1050.	0.002	L	0.111
Pb	0.013	0.019	H	1.5	0.080	H	6.1	0.185	H	14.	0.165	H	12.7
Zn	0.002	0.002	-	1.0	0.004	H	2.0	20.6	H	10300.	0.001	L	0.5
Cl	0.124	0.048	L	0.39	0.974	H	7.8	0.153	H	1.2	0.029	L	0.234
SO_4	6.74	7.81	H	1.2	22.0	H	3.3	27.0	H	4.0	2.32	L	0.344
%Low			23%L			38%L			8%L			61%L	

* Percent leached = total mg of constituent leached/mg constituent loaded into column (x100); data from Appendix A.

** T/U = percent leached from treated sludge column/percent leached from untreated sludge column.

† H or L = percent leached from treated sludge column in higher or lower than that from untreated sludge column.

the final product. As can be seen, fewer constituents are effectively contained by the treatment processes as determined using the percent lost. Process D is still judged moderately effective in isolating the sludge constituents; however, the greater part of the effectiveness of Processes A and B is lost in that a higher percentage of a majority of the constituents measured was lost from these columns than from the untreated sludge (control) columns. Process C lost more than 10 percent of over half of the constituents analyzed, including about 20 percent of the cadmium, nickel, and zinc and 43 percent and 27 percent of the magnesium and sulfate, respectively. Evidently a large part of the benefit of the treatment processes can be accounted for by simple dilution of the sludge solids by treatment additives.

The relative difficulty for the containment of the constituents of the electroplating sludge included in this study can be estimated from the data. Constituents which were lost at lower rates or concentrations (i.e. more successfully contained) in more than 75 percent of the meaurements were arsenic, mercury, magnesium, nickel, chloride and sulfate. Lead and zinc were contained almost as well. Those constituents which proved to be most difficult to contain by all treatments were beryllium, cadmium, chromium, copper and sulfate. These parameters were more prevalent in treated sludge leachates from a majority of the treatments.

Nickel-Cadmium Sludge (No. 300) Leach Testing Results

The leachate from the columns containing untreated nickel-cadmium sludge was found to have worst-case, highest single concentrations of several constituents which equaled or exceeded the drinking water standards (Table 21); these were cadmium, manganese, selenium, chloride, and sulfate. Also present at levels sufficient to cause concern were nickel and nitrate and nitrite. However, the only constituent which had an overall average concentration at an excessive level was sulfate, which had average levels of 16 times the drinking water standard (250 ppm). The low levels of most heavy metals and calcium in the leachate from the untreated sludge column may reflect the high pH values of the leachate samples (averaging 12.2) and the channelization in, and compaction of, the sludge solids (the average leachate sample size in the first one-half of the study was less than 250 ml).

Process A was generally ineffective in lessening the loss of the majority of the constituents analyzed (Table 22). Two-thirds of the constituents had higher "overall" and "highest" concentrations in the leachate from the treated sludges than in that from the untreated sludges. Calcium, chromium, manganese, zinc, and cyanide showed concentrations 7.5 to 33 times those for control leachates. Those constituents which were found at lower levels in leachates from treated sludges were lower in both "overall" and "highest" concentrations. These included copper, nickel, chloride, and sulfate.

Process B was more successful at containing the constituents analyzed. Those elements found at lower "overall" and "highest" concentrations in leachate from the treated sludges were cadmium, calcium, mercury, magnesium,

TABLE 21. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM TREATED AND UNTREATED, PRIORITY COLUMNS CONTAINING NICKEL-CADMIUM BATTERY SLUDGE (NO. 300)

Constituent	Untreated Sludge* Column		Process A Column		Process B Column	
	Overall**	Highest	Overall	Highest	Overall	Highest
Be	ID†	0.0002	0.004	0.047	ID	0.0004
Ca	15.3	85.7	302.	1280.	225.	618.
Cd	0.010	0.050	0.043	0.226	0.002	0.0083
Cr	0.001	0.004	0.018	0.099	0.010	0.047
Cu	0.013	0.080	0.012	0.076	0.004	0.025
Hg	0.011	0.057	ID	0.0003	ID	0.0038
Mg	0.610	1.20	1.13	4.70	0.022	0.100
Mn	0.006	0.122	0.061	0.922	0.002	0.016
Ni	0.314	2.90	0.024	0.111	0.012	0.130
Pb	0.003	0.019	0.003	0.026	0.052	0.899
Se	0.006	0.020	0.010	0.073	ID	0.003
Zn	0.006	0.050	0.134	1.640	0.009	0.070
Cl	35.1	704.	8.97	32.0	13.3	87.0
CN	0.002	0.010	0.015	0.110	0.024	0.14
$N-NO_3$	ID	1120.	ID	ID	ID	1190.
$N-NO_2$	ID	280.	ID	ID	ID	169.
SO_4	4070.	16500.	499.	1300.	4.69	15.0
COD	ID	472.	ID	ID	ID	ID
TOC	ID	144.	ID	ID	ID	ID

* In mg/l.

** Overall is total mg leached/total l leachate collected; highest is highest concentration found in any sample.

† ID = insufficient or no data.

TABLE 22. COMPARISON OF OVERALL AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS LEACHED FROM TREATED, NICKEL-CADMIUM BATTERY SLUDGE (NO. 300), PRIORITY COLUMNS WITH THOSE LEACHED FROM UNTREATED CONTROL COLUMNS

	Overall Concentration*				Highest Concentration			
	Process A Column		Process B Column		Process A Column		Process B Column	
Constituent	High or Low	T/U**	High or Low	T/U	High or Low	T/U	High or Low	T/U
Be	ID†		ID		H††	240.	H	2.0
Ca	H	20.	H	15.	H	15.	H	7.2
Cd	H	4.3	L	0.20	H	4.5	L	0.17
Cr	H	18.	H	10.	H	25.	H	12.
Cu	L	0.92	L	0.31	L	0.95	L	0.31
Hg	ID		ID		L	0.005	L	0.067
Mg	H	1.8	L	0.036	H	3.9	L	0.083
Mn	H	10.	L	0.33	H	7.5	L	0.14
Ni	L	0.076	L	0.038	L	0.038	L	0.045
Pb		1.0	H	17.	H	1.37	H	47.
Se	H	1.6	ID		H	3.65	H	0.15
Zn	H	22.	H	1.5	H	33.	H	1.4
Cl	L	0.25	L	0.38	L	0.045	L	0.12
CN	H	7.5	H	12.	H	11.	H	14.
SO_4	L	0.12	L	0.001	L	0.078	L	0.001

* In mg/l overall is total mg leached/total l leachate collected; highest is highest concentration found in any sample.

** T/U = amount in treated sludge column leachate/amount in untreated sludge column leachate.

† ID = insufficient or no data.

†† H or L = amount in leachate from treated sludge column is higher or lower than sludge column leachate/amount in untreated sludge leachate.

manganese, nickel, chloride, and sulfate. Only cadmium, chromium, lead, zinc, and cyanide were lost at higher levels from the treated sludges.

By calculating comparable amounts lost for each constituent using the percentage leached from each column (Table 23), the benefit due to treatment was found to be smaller. Both treatment systems lost larger proportions of 80-90 percent of the constituents analyzed than the control columns. However, very low loss rates from the untreated control column are again evident. More than one-tenth of one percent of only two constituents (calcium and mercury) was lost, and for a majority of constituents, less than one hundreth of one percent was lost over the entire leaching experiment.

Pigment Production Sludge (No. 700) Leach Testing Results

The high levels of heavy metals present in the pigment production sludge are also evident in the leachates from the untreated sludge column (Table 24). Cadmium, chromium, manganese, lead, selenium, and sulfate are typically well above drinking water standards in "overall" and "highest" concentrations. Calcium and magnesium levels are also very high, having overall concentrations of 492 and 470 (mg/l), respectively. Disposal of the pigment production sludge presents a serious pollution problem.

The only treatment system used with the pigment production sludge was Process C which acidified the sludge and than attempted to contain it in a urea-formaldehyde resin. This process was somewhat successful in limiting the overall level of arsenic, calcium, magnesium, chloride, and sulfate in the leachate, although only chloride was held to less than 50 percent of the control (Table 25). Note that the overall average concentrations of the heavy metals; cadmium, chromium, and zinc are more than 40 times that of the control.

The small relative amounts of dry sludge solids present in the treated sludge product is evident from the calculation and comparison of percent loss as seen in Table 26. Only manganese and chloride were lost in lesser amounts from the treated sludge columns. Very large relative percentages of most toxic constituents were lost from the treated column. For example, losses amounted to 10.6 percent of cadmium, 24.4 percent of the magnesium, and between 1 and 4 percent of manganese, nickel, and zinc. Further, about one-third of the calcium, magnesium and sulfate were lost from the treated sludge. These are very high values.

Another problem with the urea-formaldehyde treatment system is seen in the very high levels for total organic carbon (TOC) and chemical oxygen demand (COD) found in the leachate from the treated sludge column as seen in Table 24. Since no leachate samples from the untreated sludge columns which were tested had detectable TOC and COD; the large amounts found in the treated sludge column leachate must reflect the leaching of organics from the urea-formaldehyde polymer. Leaching of organics has previously been reported to be a problem in the solidification of radioactive wastes using this process (12).

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TABLE 23. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING TREATED AND UNTREATED NI-CO BATTERY SLUDGE (NO. 300)

	Untreated Sludge	Process A Column			Process B Column		
Constituent	% Leached*	% Leached	High or Low	T/U**	% Leached	High or Low	T/U
Be	0.001	0.69	H†	690	0.002	H	2.
Ca	0.106	27.3	H	260	13.5	H	130.
Cd	0.001	0.020	H	20	0.001	-	--
Cr	0.001	0.269	H	270	0.096	H	96.
Cu	0.007	0.083	H	12	0.019	H	2.7
Hg	0.423	0.025	L	0.06	0.143	L	0.34
Mg	0.096	2.3	H	24	0.031	L	0.32
Mn	0.006	0.79	H	130	0.016	H	2.6
Ni	0.001	0.001	-	--	0.001	-	--
Pb	0.005	0.066	H	13	0.742	H	150.
Zn	0.001	0.204	H	200	0.009	H	9.
Cl	0.051	0.169	H	3.3	0.162	H	3.2
%Low			8.3%L			16.7%L	

* Percent leached = total mg of constituent leached/mg constituent loaded into column (×100); data from Appendix A, Table A-2.

** T/U = percent leached from treated sludge column/percent leached from untreated sludge column.

† H or L = percent leached from treated sludge column in higher or lower than that from untreated sludge column.

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TABLE 24. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM TREATED AND UNTREATED, PRIORITY COLUMNS CONTAINING PIGMENT PRODUCTION SLUDGE (NO. 700)

Constituent	Untreated Sludge* Column Overall**	 Highest	Process C Column Overall	 Highest
As	0.006	0.019	0.002	0.017
Ca	492.	599.	309.	450.
Cd	0.914	1.430	40.1	96.9
Cr	0.116	0.999	5.47	20.0
Cu	0.528	0.700	2.62	16.0
Hg	0.004	0.100	0.007	0.048
Mg	720.	1050.	394.	1620.
Mn	1.83	2.80	22.5	77.0
Ni	0.310	1.210	1.96	5.70
Pb	0.872	2.300	1.038	4.2
Se	0.011	0.066	ID†	--
Zn	0.050	0.092	7.37	30.0
Cl	211.	266.	17.1	51.0
SO_4	8330.	14200.	3670.	15500.
COD	ID	BDL	ID	6900.
TOC	ID	BDL	ID	2600.

* In mg/l.

** Overall is total mg leached/total l leachate collected; highest is highest concentration found in any sample.

† ID = insufficient or no data.

TABLE 25. COMPARISON OF OVERALL AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS LEACHED FROM TREATED, PIGMENT PRODUCTION SLUDGE (NO. 700), PRIORITY COLUMNS WITH THOSE LEACHED FROM UNTREATED CONTROL COLUMNS

	Process C Column			
	Overall Conc.*		Highest Conc.	
Constituent	High or Low	T/U**	High or Low	T/U
As	L†	0.17	L	0.89
Ca	L	0.62	L	0.75
Cd	H	44.	H	68.
Cr	H	47.	H	20.
Cu	H	5.0	H	23.
Hg	H	1.7	L	0.48
Mg	L	0.55	H	1.5
Mn	H	12.	H	27.5
Ni	H	6.3	H	4.7
Pb	H	1.2	H	1.8
Zn	H	130.	H	330.
Cl	L	0.08	L	0.19
SO_4	L	0.44	H	1.09

* Overall is total mg leached/total l leachate collected; highest is highest concentration found in any sample.

** T/U = amount in treated sludge column leachate/amount in untreated sludge column leachate.

† H or L = amount in leachate from treated sludge column is higher or lower than that from untreated sludge column.

TABLE 26. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING TREATED AND UNTREATED PIGMENT PRODUCTION SLUDGE (NO. 700)

Constituent	Untreated Sludge % Leached*	Process C Column % Leached	Process C Column High or Low	Process C Column T/U**
As	0.010	0.020	H†	2.0
Ca	7.4	27.5	H	3.7
Cd	0.041	10.6	H	260.
Cr	<0.001	0.107	H	>110.
Cu	0.022	0.64	H	29.
Hg	0.023	0.21	H	9.1
Mg	7.5	24.4	H	3.2
Mn	20.4	1.46	L	0.07
Ni	0.063	2.34	H	37.
Pb	0.002	0.015	H	7.5
Zn	0.004	3.79	H	950.
Cl	0.123	0.059	L	0.48
SO_4	14.9	38.7	H	2.6
%Low			15%L	

* Percent leached = total mg of constituent leached/mg constituent loaded into column (×100); data from Appendix A.

** T/U = percent leached from treated sludge column/percent leached from untreated sludge columns.

† H or L = percent leached from treated sludge column is higher or lower than that from untreated sludge column.

Chlorine Production Sludge (No. 800) Leach Testing Results

Although this waste itself is not particularly high in heavy metals, samples of leachates from untreated chlorine production sludge exceeded drinking water standards for cadmium, chromium, copper, lead and selenium (Table 27). Also extremely high "overall" and "highest" levels of the anions, chloride, and sulfate were found. The overall level of sulfate was 5 g/l and chloride near 3 g/l. Evidently large concentrations of monovalent cations (esp. sodium) were being lost concomitantly since the loss of calcium held steady between 500 and 600 mg/l throughout the experiment.

Processes A and B had similar but only moderate success in containing the constituents from the chlorine-production sludge (Table 28). From one-half to two-thirds of the constituents had lower "overall" and "highest" concentrations in the leachates from the treated sludge columns. Beryllium, copper, mercury, lead and sulfate were most effectively contained of all the potential pollutants. Those constituents most poorly contained were arsenic, calcium, chromium, manganese, and selenium.

When calculated as percent of the dry sludge solids loaded into the column which were lost to the leaching solution (Table 29), the effectivenss of the treatments were again less evident. A larger proportion of two-thirds of the constituents were lost from the treated sludge columns. Calcium and magnesium were better contained to some extent by both treatment systems. The anions, chloride, and sulfate, were also lost to a slightly smaller degree from Process A-treated sludges; and the cations arsenic and copper contained to a greater degree in Process B-treated waste.

Glass-Etching Sludge (No. 900) Leach Testing Results

Leachates from the columns containing untreated glass-etching sludge showed high and consistent levels of calcium, magnesium, and sulfate and exceeded drinking water standards for manganese and sulfate (Table 30). Single samples were collected which had concentrations exceeding drinking water standards for chromium, manganese, lead, selenium, and sulfate. This sludge also contained large amounts of monovalent cations (particularly sodium) and fluoride which were not determined and must account for the low analytical recovery found in the bulk raw sludge analysis (Table 15). The leachates from this sludge would most likely show high levels of these constituents in the early samples since their salts are quite soluble.

As evident from Table 31, Process A treated sludges lost greater amounts and had higher peak concentrations of a majority (60-70 percent) of the constituents determined. Only chromium, magnesium, chloride, and sulfate were contained to any degree and in most of these only moderate improvements can be seen. Cadmium, copper, and lead showed concentrations in the leachate from treated-sludge columns that were 15 to 300 times those from the untreated controls.

Process B-treated wastes, in contrast, retained the majority (60-70 percent) of the constituents determined. Only copper, nickel, lead and

TABLE 27. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM TREATED AND UNTREATED, PRIORITY COLUMNS CONTAINING CHLORINE PRODUCTION SLUDGE (NO. 800)

Constituent	Untreated Sludge* Column		Process A Column		Process B Column	
	Overall**	Highest	Overall	Highest	Overall	Highest
As	0.004	0.029	0.012	0.033	0.002	0.016
Be	0.015	0.131	0.001	0.006	ID†	0.0005
Ca	531.	641.	1164.	1930.	293.	789.
Cd	0.032	0.042	0.022	0.166	0.010	20.00
Cr	0.003	0.030	0.036	0.159	0.015	0.064
Cu	0.363	2.700	0.068	0.537	0.037	0.200
Hg	0.007	0.280	0.001	0.002	0.0003	0.0027
Mg	10.7	11.4	3.10	11.20	0.035	0.300
Mn	0.013	0.030	0.120	1.820	0.011	0.062
Ni	0.131	1.160	0.120	1.300	0.033	0.165
Pb	0.217	7.100	0.095	0.600	0.026	0.999
Se	0.001	0.013	0.038	0.700	ID	0.006
Zn	0.007	0.030	0.006	0.006	ID	0.030
Cl	2780.	24000.	1100.	3970.	13030.	95500.
SO_4	4840.	32800.	1520.	4090.	3580.	24300.
COD	ID	57.	ID	ID	ID	ID
TOC	ID	54.	ID	ID	ID	ID

* In mg/l.

** Overall is total mg leached/total 1 leachate collected; highest is highest concentration found in any sample.

† ID = insufficient or no data.

TABLE 28. COMPARISON OF OVERALL AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS LEACHED FROM TREATED, CHLORINE PRODUCTION SLUDGE (NO. 800), PRIORITY COLUMNS WITH THOSE LEACHED FROM UNTREATED CONTROL COLUMNS

	Overall Concentration*				Highest Concentration			
	Process A Column		Process B Column		Process A Column		Process B Column	
Constituent	High or Low	T/U**	High or Low	T/U	High or Low	T/U	High or Low	T/U
As	H†	3.0	H	5.0	H	1.1	L	0.55
Be	L	0.06	ID††		L	0.04	L	0.004
Ca	H	2.2	L	0.55	H	3.0	H	1.2
Cd	L	0.69	L	0.31	H	3.95	H	476.
Cr	L	0.08	H	5.0	H	5.3	H	2.1
Cu	L	0.19	L	0.10	L	0.20	L	0.07
Hg	L	0.14	L	0.04	L	0.007	L	0.0096
Mg	H	3.45	L	0.0032	L	0.98	L	0.03
Mn	H	9.2	L	0.85	H	61.	H	2.07
Ni	L	0.92	H	0.25	H	1.1	L	0.14
Pb	L	0.44	L	0.12	L	0.08	L	0.14
Se	H	38.0	ID		H	54.	L	0.46
Zn	L	0.86	ID		H	2.0	H	1.0
Cl	L	0.395	H	4.7	L	0.165	H	3.97
SO_4	L	0.31	L	0.74	L	0.12	L	0.74

* Overall is total mg leached/total l leachate collected; highest is highest concentration found in any sample.

** T/U = amount in treated sludge column leachate/amount in untreated sludge column leachate.

† H or L = amount in leachate from treated sludge column is higher or lower than that from untreated sludge column.

†† ID = insufficient or no data.

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TABLE 29. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING TREATED AND UNTREATED CHLORINE PRODUCTION SLUDGE (NO. 800)

Constituent	Untreated Sludge % Leached*	Process A Column % Leached	Process A Column High or Low	Process A Column T/U**	Process B Column % Leached	Process B Column High or Low	Process B Column T/U
As	0.089	0.765	H†	8.6	0.078	L	0.87
Ca	0.78	4.28	H	5.5	0.88	H	1.1
Cd	0.21	3.5	H	16.7	1.23	H	5.8
Cr	0.13	3.7	H	28.	1.24	H	9.5
Cu	0.48	0.23	L	0.50	0.10	L	0.21
Hg	0.001	0.001	-	--	0.001	-	--
Mg	3.45	2.49	L	0.72	0.023	L	0.006
Mn	0.046	1.09	H	24.	0.081	H	1.7
Ni	0.355	0.815	H	2.3	0.185	L	0.52
Pb	1.11	1.21	H	1.09	1.15	H	1.03
Zn	0.013	0.028	H	2.1	0.018	H	1.38
Cl	7.2	7.1	L	0.99	70.	H	9.7
SO_4	37.5	29.5	L	0.79	57.6	H	1.5
%Low			31%L			31%L	

* Percent leached = total mg of constituent leached/mg constituent loaded into column (×100); data from Appendix A.

** T/U = percent leached from treated sludge column/percent leached from untreated sludge column.

† H or L = percent leached from treated sludge column is higher or lower than that from untreated sludge column.

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TABLE 30. CONCENTRATION OF SELECTED CONSTITUENTS IN LEACHATE FROM TREATED AND UNTREATED, PRIORITY COLUMNS CONTAINING GLASS ETCHING SLUDGE (NO. 900)

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	Untreated Sludge* Column		Process A Column		Process B Column	
Constituent	Overall**	Highest	Overall	Highest	Overall	Highest
As	0.006	0.008	0.033	0.243	0.001	0.017
Ca	456.	1060.	473.	608.	47.2	172.
Cd	0.002	0.006	0.030	0.230	ID†	0.0016
Cr	0.031	0.899	0.030	0.070	0.004	0.030
Cu	0.003	0.013	0.936	6.260	0.205	2.10
Mg	59.4	113.0	2.73	4.90	0.028	0.100
Mn	0.060	0.114	0.178	2.620	0.002	0.010
Ni	0.361	1.180	0.749	2.900	4.92	21.00
Pb	0.003	0.050	0.253	1.900	0.003	0.030
Se	0.003	0.013	0.005	0.030	--	0.007
Zn	0.015	0.069	0.069	0.600	0.007	0.040
Cl	11.5	43.0	3.53	21.00	35.03	285.
SO_4	921.	2190.	914.	1800.	383.	1094.
COD	ID	BDL	ID	ID	ID	ID
TOC	ID	BDL	ID	ID	ID	ID

* In mg/l.

** Overall is total mg leached/total l leachate collected; highest is highest concentration found in any sample.

† ID = insufficient data.

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TABLE 31. COMPARISON OF OVERALL AND HIGHEST CONCENTRATIONS OF SELECTED CONSTITUENTS LEACHED FROM TREATED, GLASS ETCHING SLUDGE (NO. 900), PRIORITY COLUMNS WITH THOSE LEACHED FROM UNTREATED CONTROL COLUMNS

	Overall Concentration*				Highest Concentration			
	Process A Column		Process B Column		Process C Column		Process D Column	
Constituent	High or Low	T/U**	High or Low	T/U	High or Low	T/U	High or Low	T/U
As	H†	5.5	L	0.16	H	30.	H	2.1
Ca	H	1.03	L	0.10	L	0.57	L	0.16
Cd	H	15.	ID††		H	38.	L	0.26
Cr	L	0.97	L	0.13	L	0.08	L	0.03
Cu	H	312.	H	68.	H	480.	H	160.
Mg	L	0.046	L	0.001	L	0.043	L	0.001
Mn	H	2.96	L	0.03	H	23.	L	0.084
Ni	H	2.0	H	13.6	H	2.4	H	17.
Pb	H	84.	H	1.0	H	38.	H	6.0
Se	H	1.6	ID		H	2.3	L	0.538
Zn	H	4.6	L	0.46	H	8.7	L	0.579
Cl	L	0.31	H	3.0	L	0.49	H	6.6
SO_4	L	0.99	L	0.415	L	0.82	L	0.499

* Overall is total mg leached/total 1 leachate collected; highest is highest concentration found in any sample.

** T/U = amount in treated sludge column leachate/amount in untreated sludge column leachate.

† H or L = amount in leachate from treated sludge column is higher or lower than that from untreated sludge column.

†† ID = insufficient or no data.

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chloride were lost in higher "overall" and "highest" concentrations from the treated-sludge columns. Process B most successfully contained chromium and magnesium which were generally found at an order of magnitude lower concentration in the treated sludge leachates.

The effect of taking into account the amount of dry sludge solids actually added to the columns by calculating the percentage of each constituent lost from the treated and untreated sludge columns again greatly lessened the assessment of containment effectiveness of both treatment processes (Table 32). Process A treated sludges lost a higher percentage of all constituents except magnesium from the leaching column. Sludges tested by Process B lost a higher percentage of all constituents except calcium, chromium, magnesium, and manganese.

SUMMARY OF CHEMICAL LEACHING DATA

Considerable variation was found in the ability of the treatment processor to lower the leaching loss of inorganic contaminants from the sludges used in this study. Table 33 summarizes the percentages of those constituents which were leached at lower rates from treated sludge columns than from similar untreated sludge columns. Process A had quite variable success--containing the electroplating sludge to a fairly high degree but losing contaminants to a higher degree than the control columns for the untreated Ni-Cad battery and the glass etching sludges. There was very little difference between the loss of constituents from the Process A-treated and the untreated chlorine production sludges. This variablity is also apparent in the wide ranges of the relative loss rates as seen in overall leachate concentrations shown in Figure 13. For sludges treated by Process A, the relative loss of each constituent as seen in Figure 14 varies by a factor of over 100 between sludges. Only mercury, magnesium, chloride, and sulfate were leached at lower "overall" concentrations from at least three of the four treated sludge columns; while calcium, cadmium, chromium, manganese, and selenium had higher individual concentrations from the treated sludge columns.

Results from columns containing sludges treated by Process B were more consistent than others with 60 to 70 percent of the leachate constituents having relatively lower "overall" and "highest" levels in leachates from treated sludge columns (Table 33). Again, the electroplating sludge was most successfully contained with 70 to 80 percent of the leachate values lower than the controls. Although still exhibiting considerable variations, the relative containment values displayed by Figures 15 and 16 grouped to a greater degree than similar display of the same values from Process A-treated sludge columns (Figures 13 and 14). Calcium, cadmium, magnesium, manganese, nickel, lead, zinc and sulfate were lost to the leaching medium at lower overall concentrations than control columns from at least three of the four treated sludge columns; while only chromium and copper were lost at higher "overall" concentrations from a majority of the treated sludge columns.

TABLE 32. PERCENT OF SELECTED CONSTITUENTS LEACHED FROM PRIORITY COLUMNS CONTAINING TREATED AND UNTREATED GLASS ETCHING SLUDGE (NO. 900)

	Untreated Sludge	Process A Column			Process B Column		
Constituent	% Leached*	% Leached	High or Low	T/U**	% Leached	High or Low	T/U
As	0.048	1.86	H†	38.7	0.094	H	1.96
Ca	2.3	16.5	H	7.2	1.95	L	0.84
Cd	0.060	6.7	H	112.	0.073	H	1.2
Cr	0.053	0.341	H	6.4	0.051	L	0.96
Cu	0.001	2.03	H	2030.	0.53	H	530.
Mg	0.950	0.29	L	0.30	0.004	L	0.004
Mn	0.037	0.73	H	20.	0.008	L	0.21
Ni	0.081	1.14	H	14.	8.9	H	110.
Pb	0.002	0.83	H	415.	0.14	H	70.
Zn	0.004	0.13	H	3.2	0.015	H	3.7
Cl	0.011	0.024	H	2.2	0.28	H	25.
SO_4	3.9	26.3	H	6.7	13.1	H	3.4
%Low			8.3%L			33%L	

* Percent leached = total mg of constituent leached/mg constituent loaded into column (×100); data from Appendix A.

** T/U = percent leached from treated sludge column/percent leached from untreated sludge column.

† H or L = percent leached from treated sludge column is higher or lower than that from untreated sludge column.

TABLE 33. SUMMARY OF PERCENT OF CONSTITUENTS LEACHED AT LOWER CONCENTRATIONS FROM TREATED SLUDGE SPECIMENS THAN FROM UNTREATED SPECIMENS

Sludge Type	Parameter	Process A	Process B	Process C	Process D
Electroplating (200)	Overall	93	77	36	92
	Highest	79	79	43	93
	Percent	23	38	8	83
Ni-Cad Battery (300)	Overall	31	59	*	*
	Highest	33	60	*	*
	Percent	8	17	*	*
Pigment Production (700)	Overall	*	*	38	*
	Highest	*	*	31	*
	Percent	*	*	15	*
Chlorine Production (800)	Overall	66	66	*	*
	Highest	53	60	*	*
	Percent	33	33	*	*
Glass Etching (900)	Overall	31	64	*	*
	Highest	38	62	*	*
	Percent	8	33	*	*

* Not processed by that treatment system.

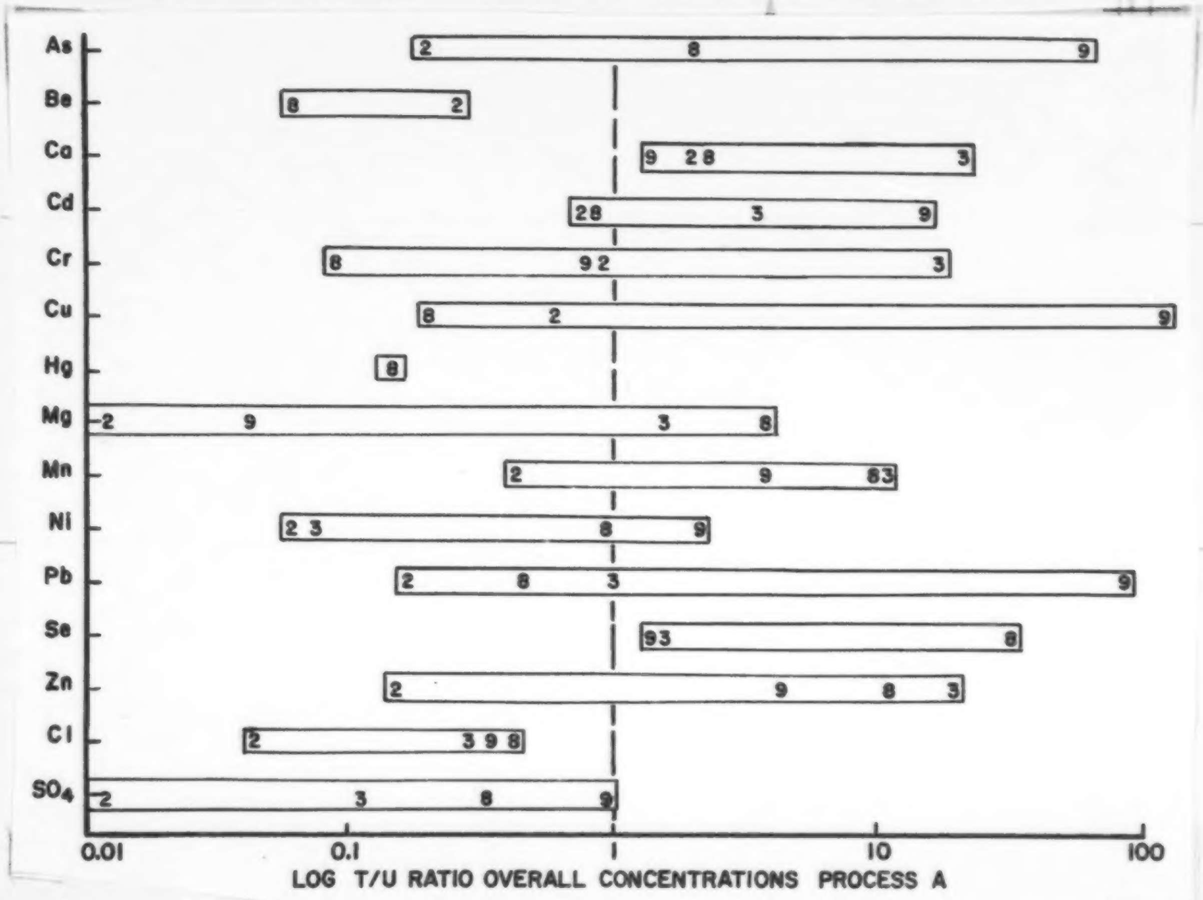

Figure 13. Plot of ratio of overall concentration of each constituent in the leachate from Process A-treated columns (T) to the corresponding value for the constituent in leachate from untreated column (U). The numbers refer to the first digit of sludge identification number.

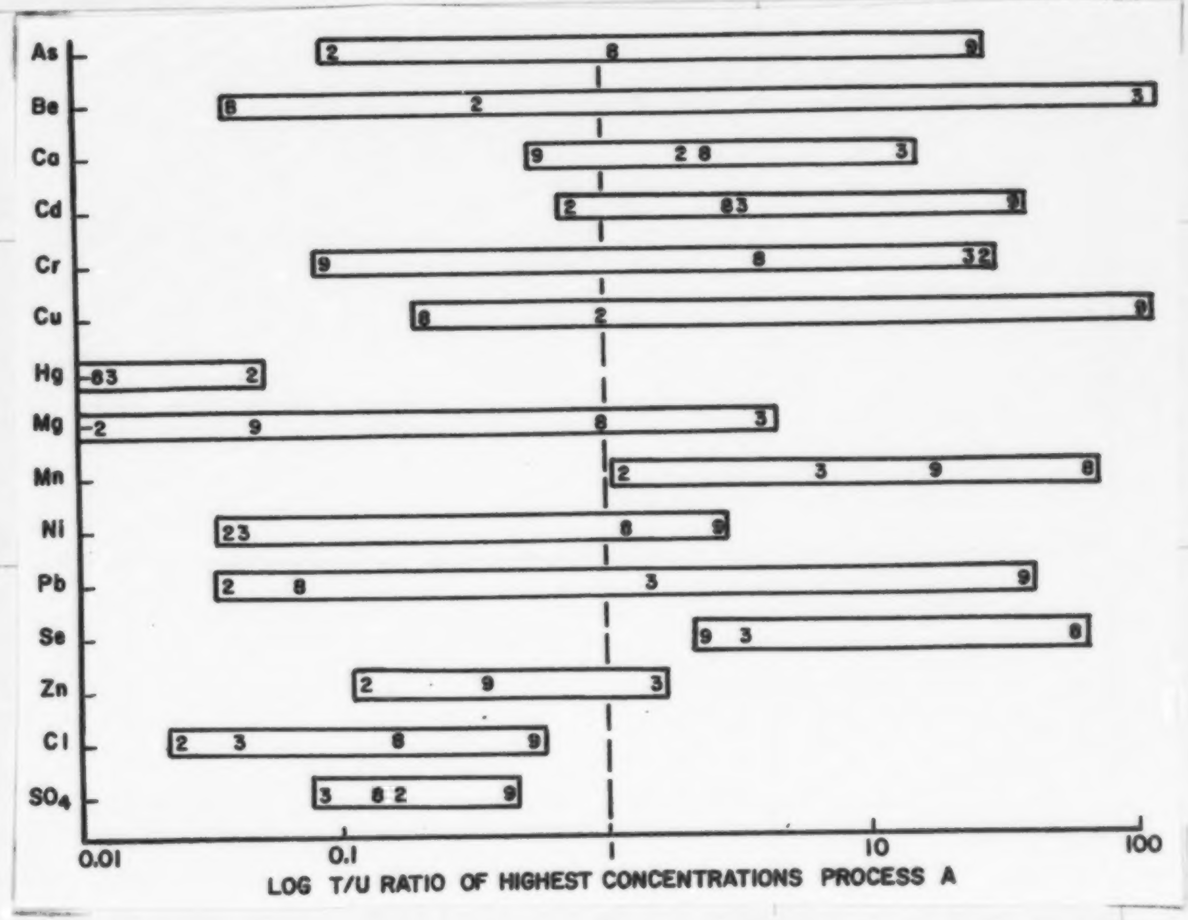

Figure 14. Plot of ratio of highest concentration of each constituent in the leachate from Process A-treated columns (T) to the corresponding value for the constituent in leachate from untreated column (U). The numbers refer to the first digit of sludge identification number.

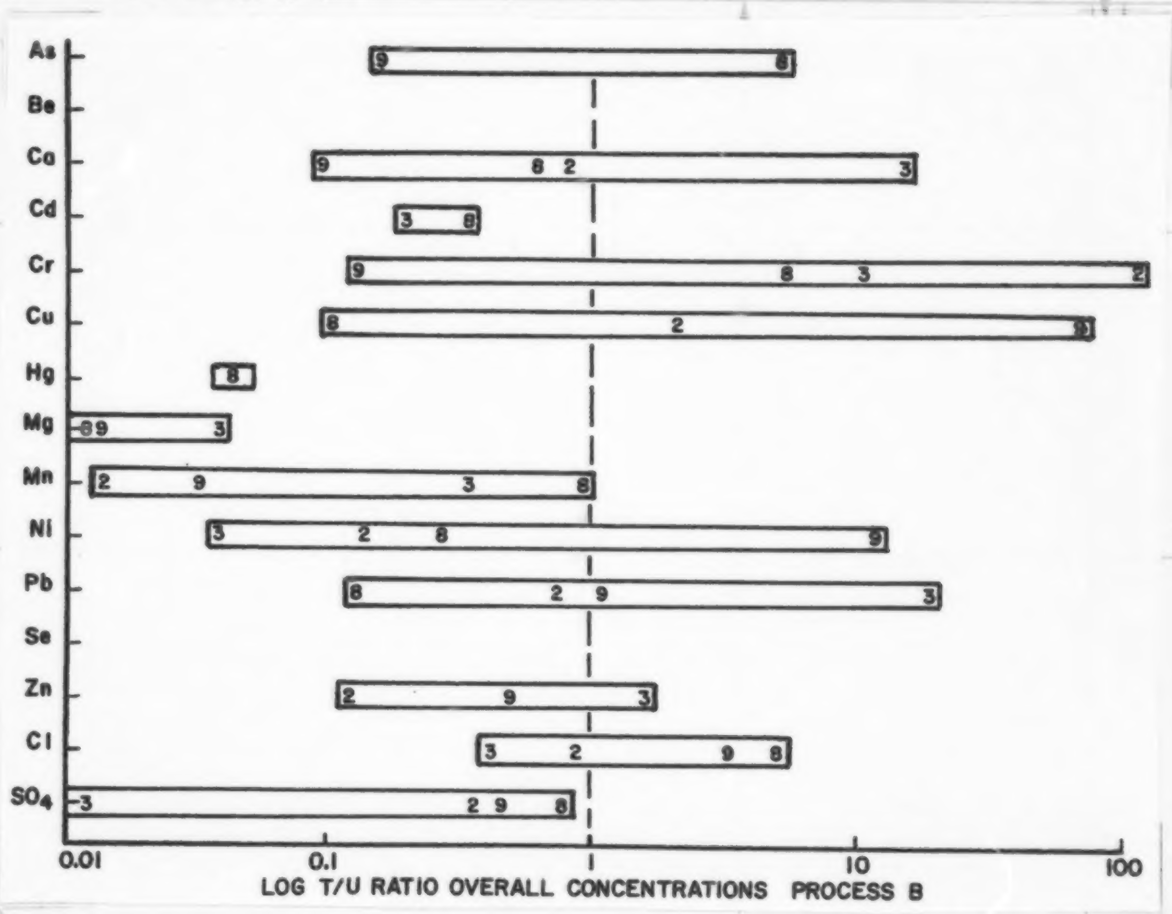

Figure 15. Plot of ratio of overall concentration of each constituent in the leachate from Process B-treated columns (T) to the corresponding value for the constituent in leachate from untreated column (U). The numbers refer to the first digit of sludge identification number.

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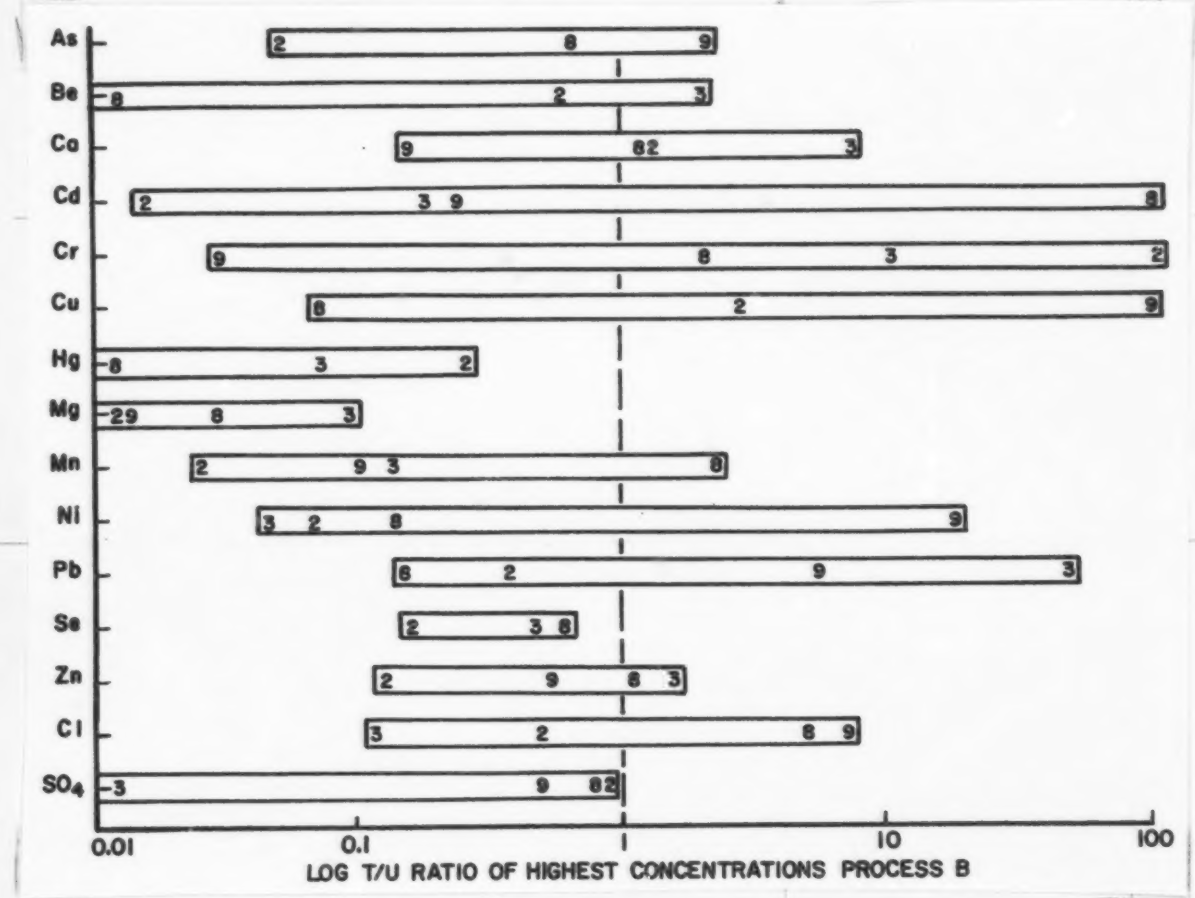

Figure 16. Plot of ratio of highest concentration of each constituent in the leachate from Process B-treated columns (T) to the corresponding value for the constituent in leachate from untreated column (U). The numbers refer to the first digit of sludge identification number.

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A high degree of correlation is seen between T/U ratios calculated from "highest" and "overall" concentrations for either sludges treated by Process A (Figure 17) and Process B (Figure 18). The data were converted to logarithms so that smaller values would be equally weighted in the analysis. The correlation coefficients for "overall" leachate concentration (0.924) and "highest" concentration (0.852) show that columns having "overall" leachate concentrations much higher (or lower) in the treated column leachate have a very high probability of also having a proportionately higher (or lower) "highest" concentration. Both measures therefore appear to be comparable measures of containment.

Little correlation is found if the values for the same constituents are compared between leachates from sludges treated by Process A or by Process B. As seen in Figure 19, a plot of the log of the "overall" concentrations of constituents in leachates from Process A-treated sludges against the same values from Process B-treated sludges gives a very wide scatter (correlation coefficient = 0.369). The same wide scatter is seen in a comparison of "highest" concentrations of percent leached values as might be expected. There seems to be little relationship between the two treated products.

Comparison of the relative containment effectiveness between treatment Processes A, B, C, and D can be made using data from the electroplating sludge (200) since this sludge was treated by all four processors. Comparative data are presented for "overall" T/U values in Figure 20 and for "highest" T/U values in Figure 21. Process D gave the best containment having less than one-tenth the "overall" amount leached for 11 of 13 of the constituents analyzed, and less than one-tenth the "highest" value found for 9 of the 13 constituents. Process C was least effective by a wide margin, having both "overall" and "highest" leachate concentrations over ten times those of the control sludge leachates in 7 of 13 cases and the highest "overall" leachate concentration in 11 of 14 cases. Processes A and B were both moderately successful at containment, each having the lowest and the highest T/U ratios for 1 to 3 of the 14 parameters measured.

Of the three parameters calculated for use in the comparison of the sludge leaching specimens--the "overall" leachate concentration, the "highest" single leachate concentration, and the percent of each sludge constituent leached--the latter, the percent leached is the most rigorous test of the effectiveness of the treatment processes. This parameter which takes into account the actual amount of waste material in the final product, consistently lessened the estimate of effectiveness of the treatment. Only one treatment system reduced more than 50 percent of the constituents measured in the leachate when calculated on a percent lost basis. All other treatment processes lost constituents at statistically higher rates than the untreated sludges when tested in the manner used in this study. Evidently, the dilution factor due to the stabilization additives is greater than the average containment effect of almost all of the treatments. On this basis eight of the eleven treatments lost higher percentages of the constituents analyzed than the untreated control sludges.

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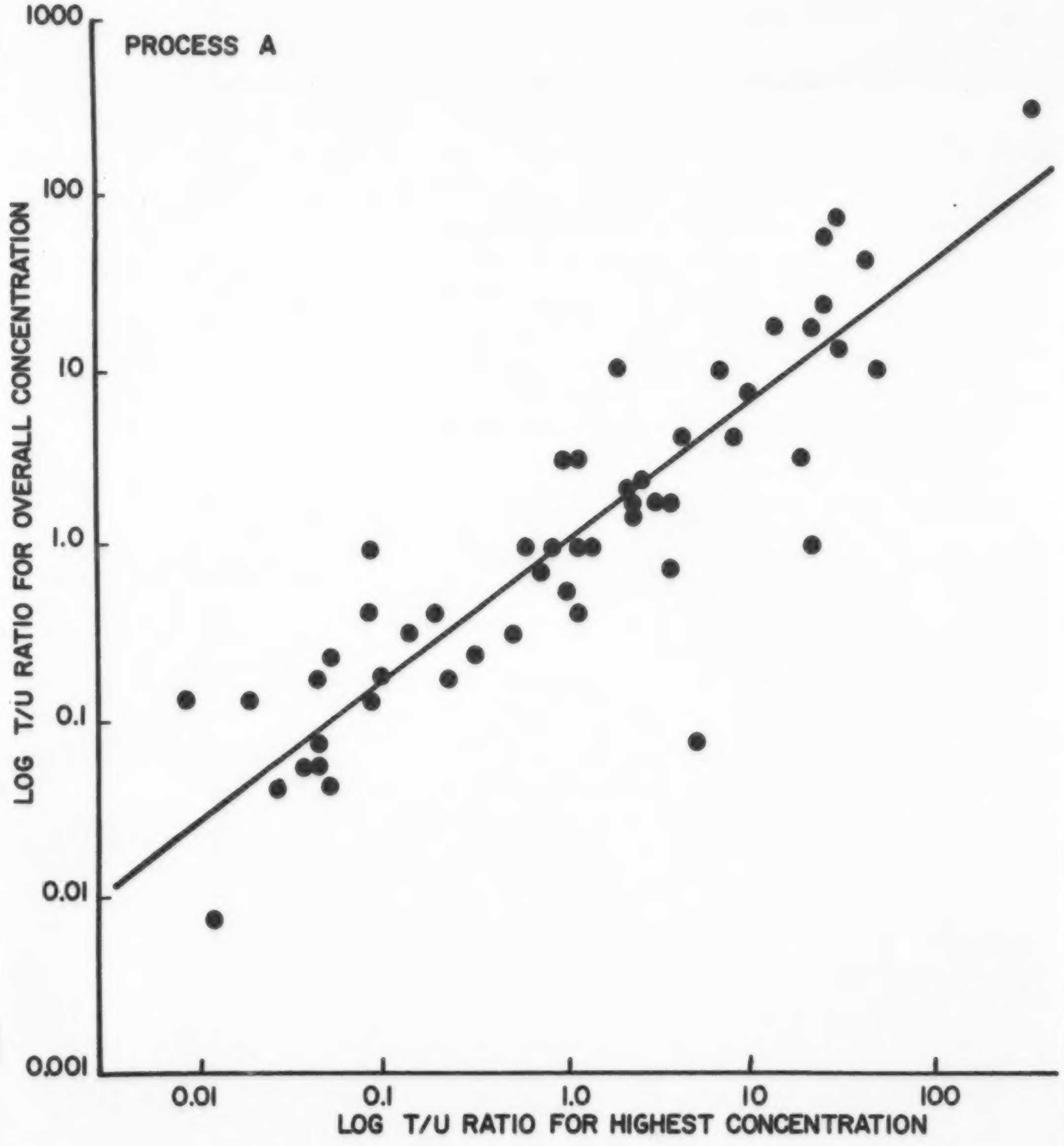

Figure 17. Plot of correlation of ratios of overall and highest leachate concentrations from treated (T) sludge columns to those from untreated (U) sludge columns for all sludges treated by Process A.

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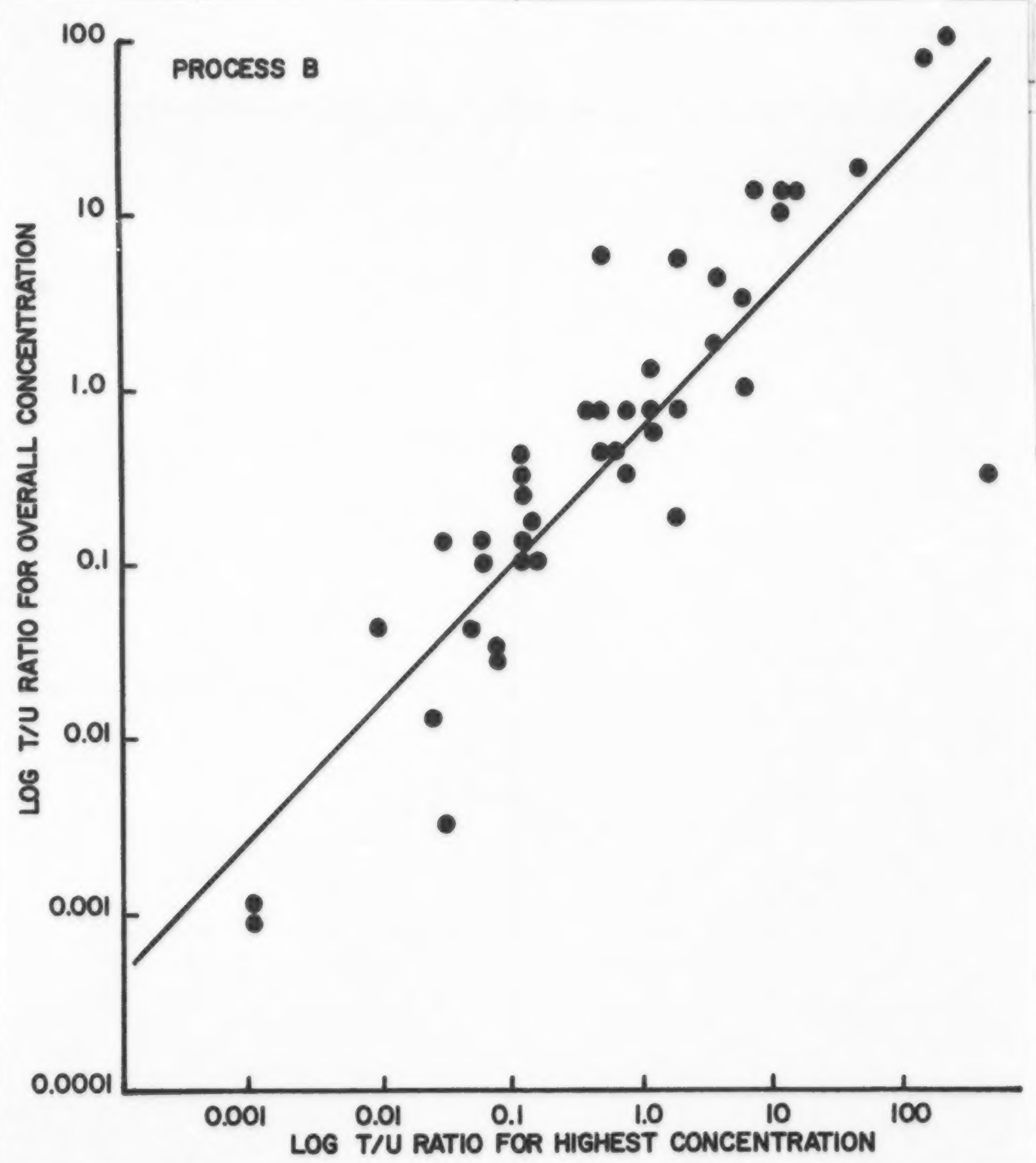

Figure 18. Plot of correlation of ratios of overall and highest leachate concentrations from treated (T) sludge columns to those from untreated (U) sludge columns for all sludges treated by Process B.

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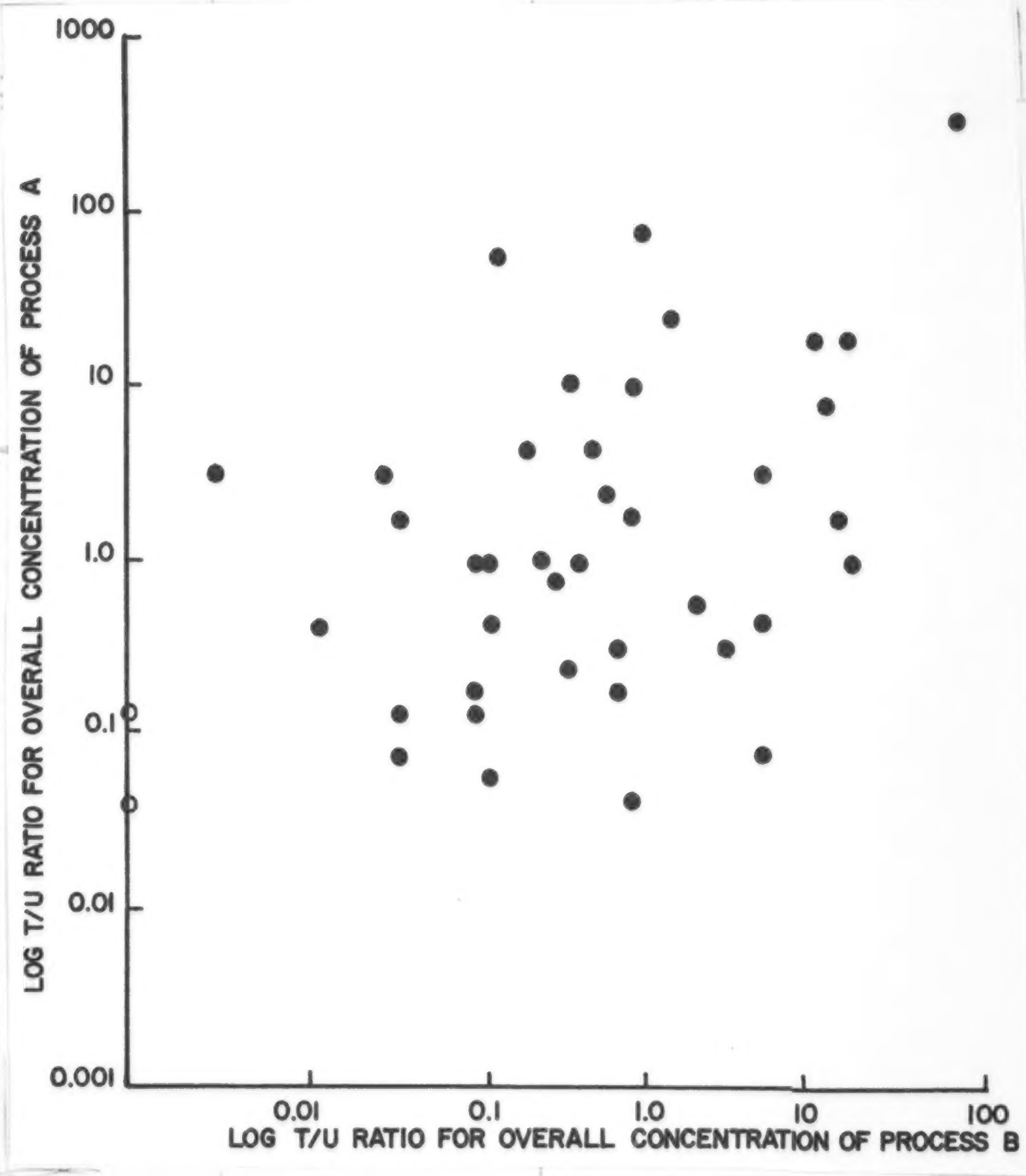

Figure 19. Plot of correlation of ratios of overall leachate concentration from sludge columns treated by Process A to corresponding values from sludge columns treated by Process B.

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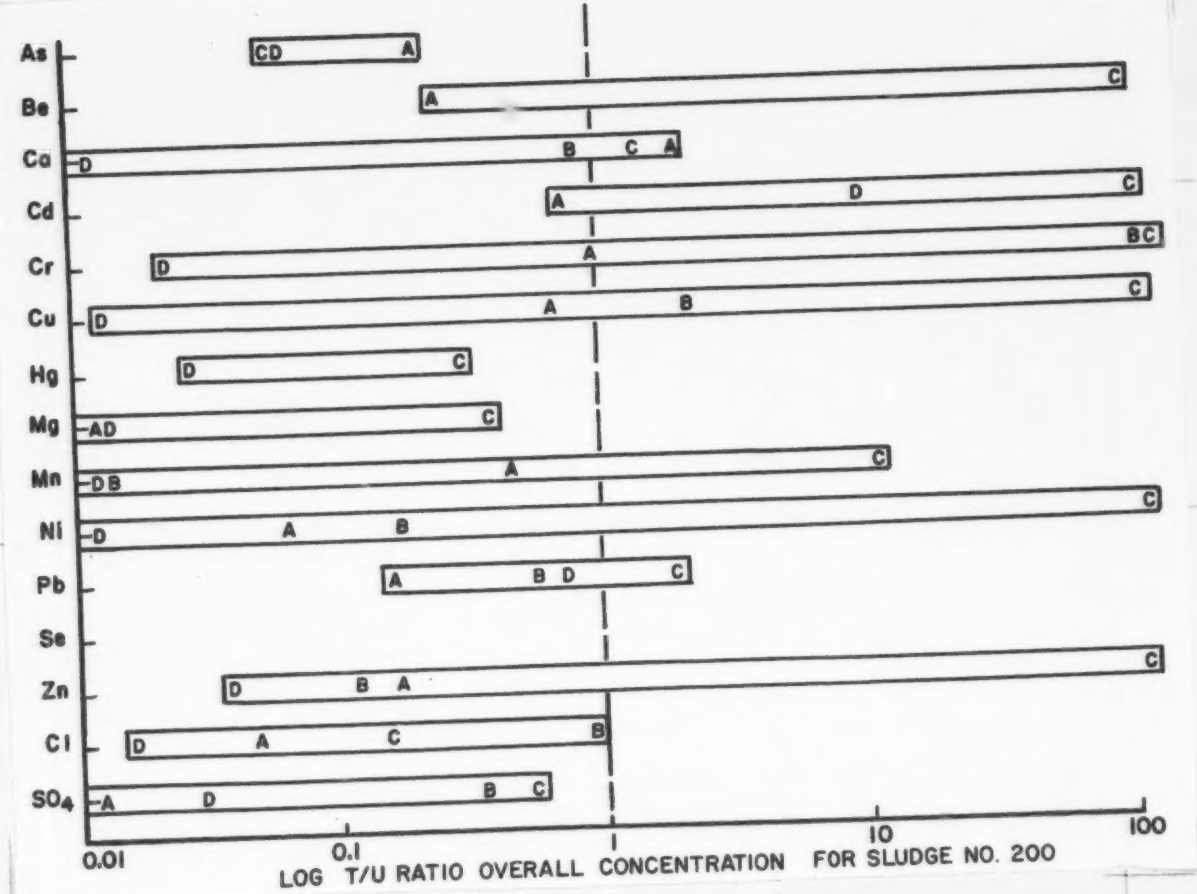

Figure 20. Plot of ratio of overall concentration of each constituent in the leachate from treated (T) electroplating sludge (No. 200) columns to corresponding values for constituents in leachate from untreated column (U). The letters refer to the process used in solidification/stabilization.

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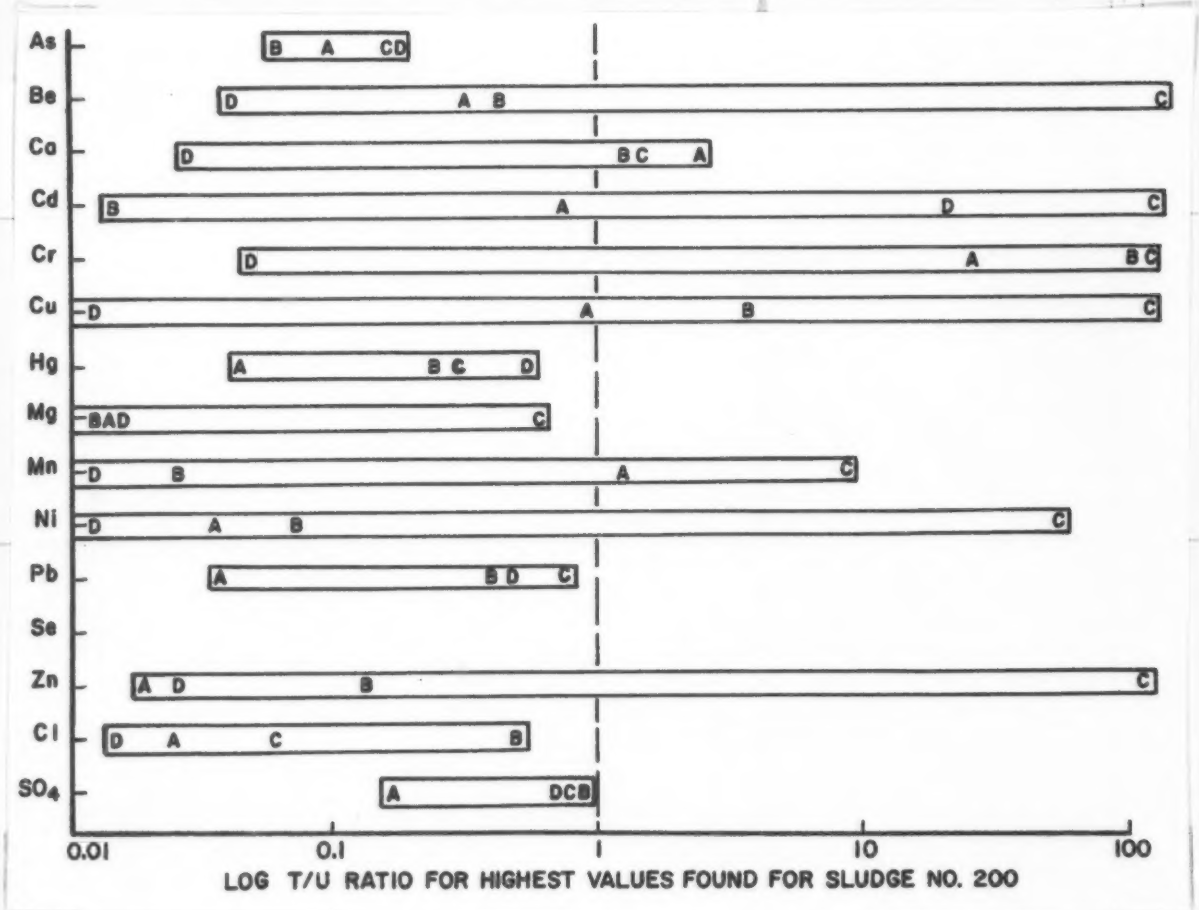

Figure 21. Plot of ratio of highest concentration of each constituent in the leachate from treated (T) electroplating sludge (No. 200) columns to corresponding values for constituents in leachate from untreated columns (U). The letters refer to the processes used in solidification/stabilization.

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The poor showing of the treatment processes used in this study can probably be related to the low leach rates of most constituents from the untreated sludges. Although appreciable amounts of most constituents were lost from the untreated-sludge columns, higher rates of loss of most constituents would be expected. The small losses from untreated control columns must be related to the very low permeability of the settled sludges, to the resulting small volumes of leachate which did flow through, and to the channeling of the leachate flow.

Dyes (fluorocene and rhodomine) added to the untreated sludge columns at the end of the experiment indicated uneven and channelized flow of the leachate through the settled sludge. The dye showed up in the effluent and in pockets along the sides of the columns long before a complete void-volume of leaching medium with dye had entered the sludge. Actual transit times and surface areas exposed to the flowing leaching medium are therefore impossible to estimate with any degree of accuracy.

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SECTION 7

DISCUSSION

GENERAL COMMENTS

The overall aim of this study was to evaluate the effect of several proposed and currently available containment technologies on the physical properties and leaching behavior of several inorganic, industrial wastes which are difficult to dispose of by conventional ponding or shallow land burial. The experimental procedures for the leaching tests were designed to simulate shallow burial conditions in saturated soils with flow rates of approximately 10^{-5} cm/sec. Such flow rates would be expected in landfills located in the eastern U. S. A study focusing on flue gas cleaning sludges from different coal and desulfurization process types, and including many of the same treatment technologies used in this study was carried out at the same time; the report of this aspect of work has already been published (2). Aspects of the work reported here also have previously been addressed at several EPA symposia (13, 14, 15) and in prior reports (8, 11).

Four waste stabilization/solidification systems which use very different containment schemes were included in the study. One, Process A, used pozzolonic flyash and lime to produce a solid waste product with good structural integrity and low pH which would render most heavy metals insoluble. The physical strength of the solidified material could be varied depending upon the needs of the final product by changing the proportion of additives; the product used in this study was designed by the processor to be typical of that which would be used in waste treatment for disposal in a shallow landfill or monofill. The unconfined compressive strength of these products varied between 18 and 117 N/cm^2 (averaging 70 N/cm^2) which is typical of a low-strength concrete. The waste products generally had a high percent solids (averaging 78 percent, about twice that of the untreated sludges) and relatively low but variable permeabilities (ranging down to 4×10^{-7} cm/sec). Process A solidified wastes also had quite varied success in containing the constituents in the leaching test--the relative overall loss rates of the constituents, as well as their highest concentrations typically varied by a factor of over 100. Only magnesium, chloride and sulfate were lost at lower rates from the treated sludges in three out of four treated sludge columns. Calcium, cadmium, chromium, manganese and selenium were lost at higher rates from the same number of columns. Although the patterns of leachate composition were changed by the solidificaton procedure, the overall effect was not particularly beneficial to the leaching properties of the treated sludges when compared to the untreated sludges.

Process A is probably the least expensive of the treatment systems in this study as it mainly consists of a second waste product; flyash, as its primary treatment additive. Since this study was designed to check the containment of the industrial waste constituents only, any additional constituents which might have been added in the treatment reagents were not taken into account. It is possible that an appreciable proportion of certain nonvolatile constituents such as chromium, manganese and nickel which were leached from Process A treated sludge columns may have entered the treated product via the added flyash treatment reagent. Nevertheless for most constituents measured the treatment did not prevent losses through leaching any better than the raw sludges themselves. As two waste products--the industrial waste and the flyash additives--are combined to produce a single product, Process A appears to be the most economical of the processes included in this study.

Treatment by Process B produced a semi-friable material with low strength and a soil-like consistency. Containment is said to be accomplished via "microencapsulation" in a silicate lattice so that the ultimate size of the tested product should not materially change its leaching characteristics. In some testing procedures, this product is ground to a fine powder before leaching. The products used in this study had low unconfined compressive strengths (5.5 to 22 N/cm^2), and moderate permeabilities (10^{-4} to 10^{-7} cm/sec), which are typical of porous materials. They also had the highest water content (dry weight basis) and void ratio (volume of voids/volume of solids) averaging 68 percent and 2.46 respectively.

This waste treatment procedure produced more consistent containment results with 60 to 70 percent of the constituents having lower levels in the leachates from the treated sludge columns in all cases. Those constituents most successfully contained were calcium, cadmium, magnesium, manganese, nickel, lead, zinc, and sulfate; all of these had lower concentrations in at least three of the four treated sludge column leachates than in the respective leachates from untreated control columns. Only chromium and copper were lost at higher rates from the majority of the treated sludge columns.

Process C attempted to contain the industrial wastes in a plastic matrix by polymerizing the waste directly in a urea-formaldehyde monomer preparation. The polymerized product was designed to produce a sponge-like mass which holds the waste. This system has seen application in low-level radioactive waste disposal (12) and transportation. The rubber-like solid products made for this study had the highest unconfined compressive strengths (200 to greater than 500 N/cm^2) but also the highest permeabilities (approximately 10^{-4} cm/sec). The densities of these products were much lower, and their modulus of elasticity much higher, than those of Processes A and B, perhaps because of the organic matrix.

Only two wastes were treated by Process C--the electroplating waste (No. 200) which all vendors treated, and the paint production sludge (No. 700) which only Process C treated. Leachates from sludges treated by Process C had high levels of most heavy metals. Losses from the electroplating waste treated by this process were greater than from the other three treated electroplating samples--as well as the untreated control sludge--for seven of the eight heavy metals analyzed. This was true in both the "overall" and "highest" concentration parameters. This solubilization of the heavy metals by the treatment system must result from the very low pH (less than 3) required for the polymerization of the urea-formaldehyde waste mixtures. The leachates from these products were also quite acidic, averaging pH values between 4 and 5. Leachates from these products also had high chemical oxygen demand and total organic carbon levels, indicating a continuing loss of unpolymerized additive or breakdown of the organic matrix itself.

Process D, after adding an organic resin to the waste to agglomerate it into a more easily handled form, encapsulates the waste inside a 0.64 cm-thick polyethylene jacket. The external jacket precluded most physical or engineering property tests on the solidified wastes. The encapuslated product had the lower density and incorporated the smallest amount of dry sludge solids into columns of any of the treatment systems. Only the electroplating waste was treated by this process. Process-D-treated sludge had the best overall containment of most of the constituents analyzed. It averaged "overall" and "highest" leachate concentrations better than an order of magnitude lower than control sludge leachates. Only cadmium and lead were lost at rates higher (Cd) or near (Pb) control levels.

Although Process D produced the best constituent containment results, its high material, equipment, and labor costs probably preclude its use for all but the most hazardous wastes (4). The question of the lifetime of the impervious, polyethylene coating and its interactions with the contained wastes should also be investigated. Once the outer covering is penetrated rather large constituent losses might be expected.

PREDICTING CONTAINMENT EFFICIENCY

Physical Properties as Predictors

Comparison of the results of the physical property and leaching tests show that none of the physical properties of the fixed sludges determined in this study were correlated with the containment ability of the treatment processes. Perhaps this is due to the diversity of the treatment processes included in this study. Selected physical properties might be significant in assessing the probable success of different processes using the same containment strategy. For instance, unconfined compressive strength and permeability might be excellent predictors of the efficacy of different pozzolonic waste treatment systems, but be of little value for those which encapsulate the waste materials in "microcrystaline" silicate lattices. High density (or low void ratio) might be indicative of better containment for those processes which limit leachate loss by lessening the diffusion of materials from the inside of the solidified waste block.

Freeze-thaw and wet-dry durability tests, or ones of similar nature might not be considered immediately applicable to properly buried treated wastes. Proper landfilling requires placement above the water table and below the frost line. However, either test might be a good indicator of the long term stability of the waste mass even under less rigorous landfill conditions. The long term stability of the treated waste product is a continuing problem.

Leachate pH appears to have some predictive value for the estimation of heavy metal losses from the treated sludges. Leachates from Process B-treated sludges had the most basic pH values, starting near pH 12 and averaging around pH 10; these leachates also had consistently lower concentrations of the sludge constituents. Process A treated wastes produced leachates which started with pH values around 10 and averaged near pH 8 or 9; concentrations in leachates from these products were more nearly like the control values. The leachate from Process C treated wastes which began around pH 5 or 6 and averaged between pH 4 and 5 had by far the greatest concentrations of almost all sludge constituents. The same trend is apparent for the leachates from the untreated control sludge columns--sludges producing leachates nearer pH 12 having generally lower concentrations of many of the sludge constituents in the leachates.

CORRELATION BETWEEN CONTAINMENT AND PROCESS OR SLUDGE TYPE

The successful containment of one sludge type cannot be taken as evidence that the treatment process will be successful in containing other similar sludges--even to the extent that successful limiting of a particular constituent from one treated sludge does not necessarily mean that that constituent will be contained in another sludge type. The patterns of constituent loss rates from different sludges are not similar. For example, comparison of the "overall" leachate concentrations of chromium and copper from different sludges treated by Process B (Figure 16) shows that chromium was lost at about one-tenth the rate from sludge No. 900 compared to untreated waste but was lost at over 10 times the rate of the control sludge loss from sludge No. 800. The loss patterns for copper are exactly opposite--a higher loss rate when compared to the untreated control from treated sludge No. 900 and a lower loss rate from treated sludge No. 800.

Replicate leaching tests made on samples of the same treatment batches, as was done in this study (see Appendix A), give strong evidence that the constituent leaching patterns are quite consistent when all test samples are from the same treatment batch and are subjected to the same testing protocol. Excellent agreement between replicates was found for all constituents which are present in the leachates at levels above the higher detection limits of the analysis method used for the two "non-priority" columns in each set of three. The leaching procedure used appears to give reproducible results even from the unconsolidated, untreated sludges where low, variable flow rates might be expected to produce the greatest variability.

The great variation in constituent leaching patterns from different sludges treated by the same treatment process, as well as from the same sludges treated by different treatment systems suggest that variations in leaching patterns might be expected between different batches of the same sludge type which are treated by the same treatment process but at different times and under slightly different conditions. Since only single batches of the treated sludges were used in this study, the data presented here do not address this question directly. However, it is an important consideration which should be included in any evaluation of any solidified/stabilized waste treatment technique.

LEACHING TESTS AS PREDICTORS

The leaching procedure used in this study appears to be a severe test of the containment performance of the waste treatment processes. The specific conditions and procedures used in any leaching evaluation will have a large effect on the apparent efficiency of any stabilization/solidification process. The test procedure used here requires that the specimens be constantly immersed in water saturated with carbon dioxide. This leaching medium is moderately aggressive in that it has a low pH (approximately 4.5) and forms soluble bicarbonate complexes with many alkali earth and transition metals. Constant submersion can cause reactions such as the hydration of calcium aluminum silicates present in the cement and flyash additives. These conditions also support biological activity which may accelerate the release of potential contaminants. These conditions are not typical of those found in a properly designed landfill.

The small size of the treated waste specimens used in this leaching protocol also is not typical of most landfilled, treated-wastes, especially for Process A treated wastes which are typically placed in monofills to produce a single, large waste block. The high surface-to-volume ratio of these small column specimens greatly increases the relative rate at which the wastes constituents can diffuse to the surface of the solid and be solubilized. While the results of small scale leaching tests such as these can be used with confidence when comparing results between different, like-sized treated wastes, and between different batches produced by the same treatment system, extrapolation to field conditions should only be made with great caution.

This study begins to define the comparative effectiveness of different waste treatment technologies as applied to several common, problem industrial waste sludges. The difficulties and considerations necessary in designing satisfactory physical and leaching testing protocols are also becoming apparent. Projects on a scale more nearly reproducing landfilling conditions are needed to give a complete evaluation of stabilization/solidification processes as applied to hazardous industrial wastes and to determine the reliability of bench-scale testing procedures such as those used here.

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APPENDIX A

RESULTS FROM NON-PRIORITY LEACHING COLUMNS

Samples from each treated and untreated sludge types were set up in triplicate leaching columns which underwent similar loading and leaching conditions. Low-level analysis of metal concentrations were only made on the leachates from one of each triplicate set of columns--the priority columns from which the information in the body of this report was derived. This appendix presents the results of the leaching tests from the remaining two columns of each triplicate set--the non-priority columns. Detection limits for both sets of analyses are presented in Table 6.

The data from all non-priority columns are given in a form comparable to that used for the priority columns in the body of this report in Tables A-1 through A-5. These tables show the average and the highest concentrations found for the constituents of greatest interest, and the average and highest volumes and pH values for all leachate samples collected. The average concentrations were not calculated for those constituents with fewer than five determinations. Below-detection-limit values were treated as missing data. Averages which fell below the detection limits are reported as below detection limits. Only those constituents with an appreciable number of determined values are listed in the table. Constituents not listed have too few analyses or too many values below the detection limits.

The data found for the non-priority columns follow patterns and are at levels quite comparable with the priority columns discussed in detail in the body of this report. Only a few of the more important trends will be discussed here to illustrate this confirmation of the data presented earlier. The values found for a majority of the constituents in the leachates from all five sludges were above the higher detection limits used for the non-priority analyses. The electroplating waste, the pigment production sludge and the chlorine production sludge all had 12 to 13 constituents which are consistently above the detection limits. The Ni-Cad battery and glass etching sludges had fewer (8 or 9) constituents at these higher levels.

The untreated sludge columns all had appreciably lower leachate production rates, all averaging around 1 l per sample except the chlorine production brine which averaged between 2 and 3 l per sample. This is the same pattern found for the priority columns (see Table 16) and is responsible for the number of constituents showing missing data for the untreated sludge columns. Frequently only enough leachate was available for a limited number of analyses. The flow rates through the treated sludge columns were uniformly high, again reflecting the free flow of leaching fluid through the polypropylene beads which were packed around the the fixed sludges. Complete analyses were usually available for the leachates from the treated sludge columns.

The pH values also reflect those found for the priority columns. All of the untreated sludge columns produced basic leachates which tended toward neutral as the experiment continued. The electroplating waste, pigment production and the glass etching sludges are well buffered, having initial high pH values less than one pH unit more basic than the average leachate pH. Leachates from the Ni-Cad battery and chlorine production sludges became much less basic over the course of the experiment, indicating a much lower buffering capacity against the moderately acid leaching medium.

The leaching rates and patterns of the various constituents which were found above detection limits in the leachates from treated and untreated sludge columns are quite similar to those discussed for the priority columns in the body of this report. No major inconsistencies are apparent. This is also obvious in comparisons made between the duplicate, non-priority columns in Tables A-1 through A-5. Agreement between the independent columns is excellent.

In general, Processes A and B are seen to be only moderately successful in containment of the cations in the four sludges which they treated. Differences in their containment efficiency are similar to those seen for the priority columns--Process B being better overall, especially on constituents in the glass etching sludge (No. 900). High levels of the anions, chloride and sulfate are found in all leachates from sludges treated by either processor. Again the differences between the containment loss from different sludges being as large or larger than between losses from the same sludge treated by either of the two processors.

Process C treatment is counterproductive for the containment of many heavy metals having leachate concentrations from 10 to 100 times the untreated controls for beryllium, cadmium, chromium, copper, manganese, nickel and zinc. Losses of calcium, magnesium, lead and sulfate were in the same range as the losses from control columns. Chloride was lost at much lower rates from Process C treated sludges. Again, these results parallel those of the priority columns very closely.

Although the solidification/stabilizaion processes used in this study were successful in preventing the leaching of some of the contaminants from some of the sludges, no solidification process was successful in containing all of the contaminants from any one sludge type, or in containing any one major contaminant in all sludge types treated. The same is true, but with wider ranges of values, if the highest concentrations of the constituents in any individual leachate sample are compared as reported in the body of this report for the priority columns.

TABLE A-1. AVERAGE AND HIGHEST VALUES OF SELECTED PARAMETERS FROM LOW-PRIORITY LEACHING COLUMNS CONTAINING TREATED AND UNTREATED ELECTROPLATING WASTE SLUDGE (NO. 200)

	Untreated Sludge Columns				Process A Columns				Process B Columns				Process C Columns			
	Column 87 (200R)		Column 119 (200R)		Column 32 (200A)		Column 70 (200A)		Column 15 (200B)		Column 38 (200B)		Column 57 (200C)		Column 51 (200C)	
Parameters	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest
Vol (1)	0.76	2.25	0.98	2.29	2.57	4.5	2.91	4.5	2.90	4.5	3.08	4.5	1.88	2.92	2.29	3.32
pH	8.2	8.6	8.4	8.9	8.2	9.9	8.2	9.8	9.9	11.9	9.93	11.8	4.7	5.2	4.8	5.6
Be	BDL	BDL	BDL	BDL	N	N	BDL	BDL	BDL	BDL	BDL	BDL	2.7	5.8	2.7	10.0
Cu	459	910	496	973	N	471	581	1,490	514	679	540	678	349	600	377	661
Cd	0.06	0.08	0.05	0.07	N	0.07	0.05	0.08	BDL	BDL	BDL	BDL	9.9	29.9	9.0	15.9
Cr	BDL	BDL	BDL	BDL	N	BDL	0.5	1.7	5.8	29.1	2.7	8.1	69.2	370	25.1	99.0
Ca	2.4	4.7	2.6	4.8	N	0.8	1.1	3.9	3.1	16.0	2.8	14.5	306	800	184	570
Mg	301.7	960.9	260.7	679.4	N	4.4	3.2	6.9	0.07	0.20	0.17	0.30	260	789	191	461
Mn	0.2	0.3	0.2	0.3	N	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2.8	8.2	2.3	5.1
Ni	0.3	0.4	0.5	2.2	N	BDL	BDL	BDL	BDL	0.6	BDL	0.6	48.6	160.0	36.9	78.0
Pb	BDL	1.0	BDL	1.0	N	BDL	BDL	1.0	BDL	BDL	BDL	BDL	BDL	1.0	BDL	BDL
Zn	BDL	BDL	BDL	BDL	N	BDL	BDL	BDL	BDL	BDL	BDL	BDL	146	486	118	264
Cl	N	420	N	370	BDL	26	13	26	203	520	185	479	31	60	27	60
SO_4	N	22,500	N	18,000	2,090	2,725	2,770	5,100	3,175	10,390	3,150	12,190	5,870	21,900	4,260	13,790

NOTE: BDL = Below detection limits; N = Not enough values for meaningful comparison. All in mg/l except pH and volume.

TABLE A-2. AVERAGE AND HIGHEST VALUES OF SELECTED PARAMETERS FROM LOW-PRIORITY LEACHING COLUMNS CONTAINING TREATED AND UNTREATED NICKEL-CADMIUM BATTERY SLUDGE (NO. 300)

	Untreated Sludge Column				Process A Columns				Process B Columns			
	Column 54 (300R)		Column 74 (300R)		Column 26 (300A)		Column 133 (300A)		Column 37 (300B)		Column 99 (300B)	
Parameters	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest
Vol (1)	1.19	3.75	1.21	2.98	2.65	4.5	2.49	4.5	3.14	4.5	3.02	4.5
pH	10.6	12.4	11.4	12.4	8.2	9.6	8.4	9.6	10.5	12.9	10.9	12.7
Ca	1.4	2.0	1.4	2.0	357	1300	443	1490	248	464	317	579
Cd	BDL	0.09	BDL	0.05	0.09	0.15	0.19	0.57	BDL	BDL	BDL	BDL
Mg	BDL	0.60	BDL	0.60	2.25	7.70	2.35	7.10	BDL	0.10	BDL	0.10
Mn	BDL	0.2	BDL	0.3	BDL	BDL	BDL	0.9	BDL	BDL	BDL	BDL
Ni	0.7	2.3	0.4	0.6	BDL	0.4	0.3	1.3	BDL	BDL	BDL	0.35
Pb	BDL	1.0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1.5
Cl	N	250	N	170	110	400	139	562	47	102	119	459
SO_4	N	N	N	N	1400	1675	1365	1780	N	9.0	11	21
NO_3	N	N	N	N	N	N	N	N	987	1810	360	1175

NOTE: BDL = Below detection limits; N = Not enough values for meaningful comparison. All in mg/l except pH and volume.

TABLE A-3. AVERAGE AND HIGHEST VALUES OF SELECTED PARAMETERS FROM LOW-PRIORITY LEACHING COLUMNS CONTAINING TREATED AND UNTREATED PIGMENT PRODUCTION SLUDGE (NO. 700)

	Untreated Sludge Column				Process C Column			
	Column 78 (700R)		Column 92 (700R)		Column 66 (700C)		Column 95 (700C)	
Parameter	Average	Highest	Average	Highest	Average	Highest	Average	Highest
Vol (1)	0.88	2.75	0.66	2.55	2.17	3.08	2.52	4.5
pH	8.0	8.4	7.6	8.5	6.1	7.2	4.9	5.8
Ca	517	731	515	759	348	499	235	398
Cd	0.75	1.50	0.82	1.29	31.60	57.93	36.52	53.98
Cr	0.3	1.2	BDL	1.0	0.5	1.3	21.6	80.0
Cu	0.5	0.7	0.8	1.4	0.6	1.6	4.6	9.5
Hg	BDL	0.003	BDL	0.005	0.006	0.013	0.004	0.008
Mg	638	1012	736	937	731	3390	267	545
Mn	1.6	2.5	1.9	2.9	26.1	38.1	26.9	85.0
Ni	0.3	0.8	0.4	0.8	1.6	3.4	2.4	4.0
Pb	1.2	2.3	1.3	2.0	2.1	3.5	1.9	3.8
Zn	BDL	BDL	BDL	BDL	12	40	11	20
Cl	N	260	N	260	31	51	20	51
SO_4	6,930	11,000	4,430	7,000	4,660	12,890	3,380	8,091
COD	N	N	N	N	5,610	6,822	4,225	5,234

Note: BDL = Below detection limits; N = Not enough values for meaningful comparison. All in mg/l except pH and volume.

TABLE A-4. AVERAGE AND HIGHEST VALUES OF SELECTED PARAMETERS FROM LOW-PRIORITY LEACHING COLUMNS CONTINING TREATED AND UNTREATED CHLORINE PRODUCTION SLUDGE (NO. 800)

	Untreated Sludge Columns				Process A Columns				Process B Columns			
	Column 3 (800R)		Column 77 (800R)		Column 7 (800A)		Column 94 (800A)		Column 50 (800B)		Column 118 (800B)	
Parameter	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest
Vol (1)	2.32	4.5	3.27	4.5	2.45	3.58	2.44	3.58	3.92	4.5	3.17	4.5
pH	7.7	10.3	8.0	10.0	8.6	10.4	8.4	10.2	11.3	12.5	11.7	12.6
Be	BDL	0.12	0.08	0.14	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ca	518	729	455	730	658	1,970	629	1,910	520	1,058	469	811
Cd	N	BDL	N	0.05	0.05	0.18	0.06	0.47	BDL	BDL	BDL	BDL
Cr	N	BDL	1.0	2.2	BDL	0.139	0.076	0.120	BDL	1.0	0.8	2.0
Cu	0.4	1.2	0.3	1.2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Hg	0.031	0.205	0.056	0.340	0.001	0.005	BDL	BDL	BDL	0.003	0.006	0.040
Mg	4.3	14.0	32.5	130.0	4.6	14.1	3.9	11.3	BDL	0.1	BDL	0.2
Mn	0.2	1.0	N	0.2	BDL	0.1	BDL	1.3	BDL	BDL	BDL	BDL
Ni	0.6	1.2	0.7	1.1	4.2	0.3	0.1	0.1	BDL	0.5	BDL	0.5
Pb	BDL	1.7	BDL	BDL	BDL	1.2	BDL	1.2	BDL	BDL	BDL	1.0
Cl	N	N	N	N	1,640	3,340	1,170	3,815	7,600	62,500	14,500	75,500
SO_4	N	N	N	N	3,297	6,600	2,980	3,900	3,130	23,390	5,910	27,990

Note: BDL = below detection limits; N = not enough values for meaningful comparison. All in mg/l except pH and volume.

TABLE A-5. AVERAGE AND HIGHEST VALUES OF SELECTED PARAMETERS FROM LOW-PRIORITY LEACHING COLUMNS CONTAINING TREATED AND UNTREATED GLASS ETCHING SLUDGES (NO. 900)

	Untreated Sludge Columns				Process A Columns				Process B Columns			
	Column 11 (900R)		Column 131 (900R)		Column 64 (900A)		Column 143 (900A)		Column 30 (900B)		Column 109 (900B)	
Parameter	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest	Average	Highest
Vol	1.60	4.5	1.74	4.5	2.83	4.5	2.37	4.5	2.87	4.5	2.87	4.5
pH	7.4	8.0	7.5	8.2	8.5	9.9	8.5	9.7	10.2	11.5	10.1	11.5
Ca	674	1019	662	1078	438	582	459	699	63	153	72	154
Cd	BDL	BDL	BDL	BDL	BDL	0.18	BDL	0.33	BDL	BDL	BDL	BDL
Cr	BDL	0.8	BDL	1.1	BDL	0.10	BDL	BDL	BDL	BDL	BDL	BDL
Cu	BDL	BDL	BDL	0.4	0.2	0.8	BDL	0.3	0.7	3.2	0.3	0.9
Mg	65	119	115	599	2.3	3.7	1.9	4.1	BDL	BDL	BDL	BDL
Ni	N	1.0	0.3	1.0	1.4	5.8	1.5	5.8	8.6	21.0	9.4	27.0
Cl	N	N	N	N	BDL	9	BDL	11	46	115	41	135
So$_4$	N	N	N	N	1315	1425	1430	1650	560	975	613	1089

Note: BDL = below detection limits; N = not enough values for meaningful comparison. All in mg/l except pH and volume.

APPENDIX B

PRIORITY COLUMN LOADING AND TOTAL AMOUNT LEACHED

The actual mass of each sludge constituent in the dry sludge solids which were loaded into each priority column is shown for each untreated and treated sludge in Tables B-1 to B-5. Materials added in the treatment reagents are not included since the actual composition and, in some cases, identity of these additives were not supplied by the vendor companies. Also included in the tables is the accumulated mass of each constituent leached from that column over the total leaching period. This latter number is calculated by summing the products of the concentration of each leachate sample in mg/l times the sample volume in liters. These are the values from which the overall leachate concentrations and percent leached data in Section 6 of this report were derived.

TABLE B-1. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED PRIORITY COLUMNS AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED FOR SLUDGE NO. 200 (ELECTROPLATING SLUDGE)

	Untreated Sludge Column		Process A Column		Process B Column		Process C Column		Process D Column	
Constituent	mg in col	Total mg Leached	mg in col	Total mg Leached	mg in col	Total mg Leached	mg in col	Total mg Leached	mg in col	Total mg Leached
As	87.95	0.145	36.07	0.959	46.21	0.009	30.61	0.016	17.9	0.048
Be	1,378	0.039	565.2	0.019	724.0	0.028	479.3	48.83	280	0.002
Ca	56,600	2,565	232,200	17,520	297,400	10,753	197,000	10,530	115,000	65.16
Cd	3,200	0.170	1,313	0.422	1,682	0.033	1,114	212.8	651	4.56
Cr	341,900	0.390	140,200	12.005	332,300	210.1	119,000	1,227	69,600	0.016
Cu	206,800	10.46	84,820	22.16	108,700	110.40	71,980	7,870	42,100	0.393
Hg	4.51	0.028	1.85	0.003	2.370	0.02	1.57	0.016	0.92	0.002
Mg	32,850	4,512	13,480	111.7	17,260	1.600	11,440	4,943	6,690	1.421
Mn	969.6	1.384	397.7	2.023	509.5	0.100	337.5	49.33	197	0.027
Ni	13,750	2.525	5,642	0.549	7,228	1.778	4,788	900.1	2,800	0.044
Pb	3,960	0.508	1,624	0.309	2,080	1.766	1,378	2.54	806	1.335
Zn	34,140	0.654	14,000	0.349	9,511	0.365	11,880	2,456	6,950	0.096
Cl	992,200	1,230	407,000	193.9	521,400	5,076	345,400	531.0	202,000	59.126
CN	ND	0.194	ND	6.838	ND	ND	ND	338.5	ND	0.182
SO_4	1,217,000	82,060	499,500	390.30	639,900	140,800	423,900	114,708	248,000	5,753
SO_3	ND	3.003	ND	0.009	ND	292.9	ND	314.7	ND	219.9
Avg pH (std. units)		8.22		8.24		9.34		4.30		7.12

Note: ND = no data.

TABLE B-2. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED PRIORITY COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED FOR SLUDGE NO. 300 (NICKEL CADMIUM BATTERY SLUDGE)

	Untreated Sludge Column		Process A Column		Process B Column	
Constituent	mg in col	Total mg Leached	mg in col	Total mg Leached	mg in col	Total mg Leached
As	BDL	2.099	BDL	0.284	BDL	0.008
Be	80.08	<0.001	23.19	0.160	42.35	0.001
Ca	149,500	159.0	43,340	11,840	79,160	10,690
Cd	28,620	0.102	8,294	1.680	15,140	0.089
Cr	929.5	0.013	269.3	0.724	491.9	0.473
Cu	1,982	0.137	574.4	0.479	1,049	0.197
Hg	27.66	0.117	8.02	0.002	14.63	0.021
Mg	6,585	6.330	1,908	44.31	3,484	1.066
Mn	1,046	0.061	303.2	2.405	553.8	0.091
Ni	1,040,000	3.263	301,400	0.929	550,500	0.562
Pb	627.9	0.029	181.9	0.118	332.2	2.466
Se	ND	0.061	ND	0.372	ND	0.008
Zn	8,864	0.060	2,568	5.241	4,691	0.428
Cl	719,400	363.9	214,000	351.0	390,900	633.1
CN	ND	0.020	ND	0.580	ND	1.146
SO_4	ND	42,240	ND	19,524	ND	223.3
SO_3	ND	33.53	ND	10.14	ND	93.96
Avg pH		11.54		8.87		11.01

Note: ND = no data; BDL = below detection limits.

TABLE B-3. AMOUNT OF CONSITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED PRIORITY COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED FOR SLUDGE NO. 700 (PIGMENT PRODUCTION SLUDGE)

	Untreated Sludge Column		Process C Column	
Constituent	mg in col	mg Leached	mg in col	mg Leached
As	821.1	0.080	244.8	0.049
Be	BDL	0.07	BDL	1.161
Ca	91,770	6,803	27,360	7,514
Cd	30,670	12.64	9,144	974.2
Cr	417,700	1.543	124,500	132.9
Cu	33,560	7.308	10,000	63.63
Hg	275.3	0.062	82.08	0.172
Mg	131,800	9,958	39,310	9,586
Mn	12,500	25.36	3,730	546.3
Ni	6,810	4.295	2,030	47.50
Pb	555,400	12.06	165,000	25.21
Se	ND	0.152	ND	ND
Zn	15,840	0.697	4,723	179.0
Cl	2,366,000	2,913	705,600	415
SO_4	772,800	115,200	230,400	89,080
Avg pH		7.98		5.56

Note: ND = no data, BDL = below detection limits.

TABLE B-4. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED PRIORITY COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED FOR SLUDGE NO. 800 (CHLORINE PRODUCTION SLUDGE)

	Untreated Sludge Column		Process A Column		Process B Column	
Constituent	mg in col	Total mg Leached	mg in col	Total mg Leached	mg in col	Total mg Leached
As	161.4	0.143	58.45	0.447	88.01	0.069
Be	BDL	0.578	BDL	0.044	BDL	0.001
Ca	2,678,000	20,890	969,800	41,520	1,460,000	12,840
Cd	60.71	0.127	21.98	0.770	33.10	0.407
Cr	94.91	0.122	34.37	1.274	51.75	0.641
Cu	2,972	14.28	1,076	2.443	1,621	1.629
Hg	118,700	0.280	42,980	0.033	64,730	0.013
Mg	12,240	421.8	4,434	110.5	6,677	1.514
Mn	1,092	0.499	395.5	4.309	595.5	0.481
Ni	1,453	5.158	526.2	4.287	792.3	1.469
Pb	769.3	8.556	278.6	3.376	419.5	4.834
Se	ND	0.058	ND	1.347	ND	0.011
Zn	2,061	0.263	746.3	0.205	1,123	0.205
Cl	1,519,000	109,500	550,200	39,240	828,600	580,000
CN	ND	ND	ND	0.128	ND	ND
SO_4	508,100	190,500	184,000	54,330	277,000	159,600
Avg pH		7.69	8.69			11.15

Note: ND = no data, BDL = below detection limits.

TABLE B-5. AMOUNT OF CONSTITUENTS IN DRY SLUDGE SOLIDS LOADED IN TREATED AND UNTREATED PRIORITY COLUMNS, AND TOTAL AMOUNT OF EACH CONSTITUENT LEACHED FOR SLUDGE NO. 900 (GLASS ETCHING SLUDGE)

	Untreated Sludge Column		Process A Column		Process B Column	
Constituent	mg in col	Total mg Leached	mg in col	Total mg Leached	mg in col	Total mg Leached
As	124.7	0.060	49.54	0.924	64.91	0.061
Be	BDL	0.206	BDL	0.045	BDL	0.002
Ca	203,500	4,771	80,850	13,308	105,900	2,068
Cd	31.47	0.019	12.50	0.836	16.38	0.012
Cr	617.1	0.327	245.2	0.837	321.2	0.163
Cu	3,269	0.031	1,299	26.35	1,702	9.004
Hg	17.02	ID	6.760	0.003	8.858	0.015
Mg	65,390	621.0	25,970	76.93	34,030	1.235
Mn	1,733	0.639	688.5	5.013	902.2	0.075
Ni	4,655	3.770	1,849	21.07	2,423	215.8
Pb	2,167	0.036	860.7	7.111	1,128	0.137
Se	ND	0.036	ND	0.138	ND	0.018
Zn	3,814	0.155	1,515	1.943	1,986	0.302
Cl	1,050,000	120.3	417,300	99.34	546,800	1,535
SO_4	246,100	9,630	97,800	25,729	128,100	16,800
Avg pH		7.62		8.39		11.24

Note: ND = no data; BDL = below detection limits; ID = insufficient data.

APPENDIX C

DATA SET FOR PRIORITY LEACHING COLUMNS

Tables C-1 through C-16 give the actual concentrations of all constituents analyzed in each leachate sample collected from the priority columns. Volumes, pH, and conductivities are also included. The data have been blank corrected and are presented in order of the column number. The majority of the data presentations discussed in this report are taken from the first 12 sampling periods only (first year), but the data for the second year's leaching (numbers 13-16) are included in these tables when available.

TABLE C-1. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 2 WHICH CONTAINED SLUDGE 900 TREATED BY PROCESS A.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	14.	1.5149	9.8	3300.	0.008	BDL	608.0	BDL	0.005	0.410	BDL	4.7	0.009
2.	21.	1.7730	8.7	300.	0.005	BDL	538.2	BDL	0.069	0.115	BDL	4.1	2.622
3.	28.	1.9450	9.4	2600.	0.007	0.0020	312.5	BDL	0.070	0.169	0.0006	2.8	0.003
4.	35.	2.0310	9.6	2300.	0.013	0.0007	179.3	0.2298	0.022	0.086	BDL	4.9	BDL
5.	56.	1.6869	9.3	2200.	0.012	0.0040	470.0	0.0030	0.015	0.090	0.0005	2.1	0.015
6.	77.	1.6697	8.0	2000.	0.006	BDL	588.9	BDL	0.003	0.030	0.0004	2.9	BDL
7.	133.	1.8590	8.6	2050.	0.003	BDL	479.2	BDL	0.054	0.103	BDL	1.4	BDL
8.	161.	3.2353	8.1	2310.	0.007	0.0020	269.3	0.0008	0.042	0.099	BDL	1.0	BDL
9.	196.	2.4611	7.8	3200.	0.273	0.0030	590.0	BDL	0.047	0.170	BDL	2.2	0.003
10.	259.	3.2353	6.7	2000.	0.009	0.0060	478.3	0.1000	0.047	6.260	BDL	0.9	0.015
11.	329.	3.3214	7.6	2100.	0.007	BDL	589.1	0.0021	BDL	0.110	BDL	2.4	0.018
12.	392.	3.4074	7.1	2200.	0.024	BDL	553.0	0.	BDL	0.046	BDL	2.1	0.012
13.	451.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	569.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	708.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-1. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	2,900	0,018	0,030	0,600	ND	0,53	ND	ND	ND	ND	ND	ND
2.	1,700	0,004	0,022	BDL	ND	0,49	ND	ND	ND	ND	ND	ND
3.	1,700	BDL	ND	0,010	ND	0,24	ND	ND	ND	ND	ND	ND
4.	1,100	1,899	ND	0,010	ND	0,14	ND	ND	ND	ND	ND	ND
5.	0,930	1,000	ND	0,020	21.	0,16	ND	ND	1425.	BDL	ND	ND
6.	0,670	BDL	ND	BDL	7.	ND	ND	ND	1800.	BDL	ND	ND
7.	0,534	0,004	ND	0,010	1.	0,07	ND	ND	1350.	BDL	ND	ND
8.	0,544	BDL	ND	BDL	BDL	ND	ND	ND	1291.	ND	ND	ND
9.	0,338	BDL	ND	0,025	ND	ND	ND	ND	ND	ND	ND	ND
10.	0,168	0,400	ND	0,161	BDL	ND	ND	ND	1300.	BDL	ND	ND
11.	0,236	0,006	0,007	0,029	BDL	ND	ND	ND	1241.	BDL	ND	ND
12.	0,143	0,061	0,009	0,006	15.	ND	ND	ND	1540.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-2. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 5 WHICH CONTAINED UNTREATED SLUDGE 200.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	1.	0.1385	ND	ND	ND	0.0065	412.0	0.0400	0.025	2.500	ND	220.0	0.790
2.	8.	0.2589	8.3	18800.	ND	0.0095	519.2	0.0700	0.014	0.760	ND	219.5	0.522
3.	14.	0.2934	8.5	1.	ND	0.0070	299.5	0.1100	0.020	3.229	ND	2.5	0.185
4.	21.	0.2245	8.3	18000.	ND	0.0044	479.3	0.0898	0.021	3.300	0.0010	229.3	0.192
5.	28.	0.2073	8.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	39.	0.2245	8.4	2200.	ND	0.0030	348.9	0.0400	0.019	3.700	0.0022	639.4	0.186
7.	63.	0.1557	8.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	91.	0.6374	8.2	18200.	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	126.	0.2417	8.4	18000.	ND	ND	ND	BDL	ND	BDL	ND	ND	ND
10.	189.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	245.	2.9773	8.2	15000.	ND	0.0090	359.1	0.0053	0.050	1.450	0.0003	1034.9	0.150
12.	353.	1.6869	8.0	21000.	0.001	ND	391.0	0.0105	0.095	1.086	0.0003	280.0	0.240
13.	451.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	569.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	708.	1.8590	8.2	21000.	0.077	BDL	175.3	0.0097	0.027	0.650	0.0137	363.0	0.063
16.	814.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-2. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	0.300	0.150	ND	0.280	ND	ND	ND	ND	ND	ND	ND	ND
2.	2.500	0.076	ND	ND	530.	ND	BDL	0.10	12991.	BDL	ND	ND
3.	0.300	0.051	ND	0.570	1066.	ND	BDL	0.	17500.	ND	ND	ND
4.	0.400	0.591	0.061	0.400	ND	ND	ND	ND	ND	ND	ND	ND
5.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	ND	0.975	ND	0.130	ND	ND	ND	ND	ND	ND	ND	ND
7.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	0.090	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	0.430	ND	ND	0.010	5.	0.06	ND	ND	13991.	BDL	ND	ND
12.	0.152	ND	ND	0.129	445.	ND	ND	ND	18900.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	0.053	BDL	0.646	BDL	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-3. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 9 WHICH CONTAINED SLUDGE 800 TREATED BY PROCESS B.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	7.	3,4246	12,5	110000.	BDL	BDL	190,0	0,0420	ND	0,038	0,0012	0,1	0,008
2.	14.	2,7192	12,3	108000.	0,002	BDL	358,2	BDL	0,064	0,100	BDL	BDL	0,062
3.	21.	3,9751	12,5	50000.	BDL	BDL	209,5	BDL	ND	0,049	0,0007	BDL	0,005
4.	28.	2,4955	12,4	18000.	0,002	BDL	283,3	BDL	0,062	0,200	BDL	BDL	BDL
5.	42.	2,7364	12,1	14700.	BDL	BDL	484,0	BDL	0,030	0,020	BDL	BDL	0,001
6.	56.	2,0654	13,0	9500.	BDL	BDL	788,9	BDL	ND	0,013	BDL	BDL	BDL
7.	91.	1,8590	11,3	7000.	BDL	BDL	499,2	BDL	0,009	0,018	0,0002	BDL	BDL
8.	126.	2,1310	11,4	9000.	BDL	BDL	188,3	BDL	0,003	0,050	BDL	BDL	BDL
9.	161.	1,9450	9,1	7200.	BDL	BDL	750,0	BDL	BDL	0,040	0,0027	0,3	0,005
10.	224.	1,8590	11,1	4000.	0,002	0,0005	348,3	20,0000	BDL	BDL	0,0002	ND	0,001
11.	273.	3,0977	11,2	5300.	ND	ND	539,1	0,0003	BDL	BDL	ND	BDL	ND
12.	365.	3,4074	11,2	4500.	0,016	BDL	451,0	BDL	0,055	0,026	BDL	0,0	BDL
13.	498.	4,5000	7,5	370.	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	611.	3,8375	11,4	3400.	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	735.	4,5000	8,2	500.	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-3. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	0.165	0.686	ND	0.020	95500.	ND	0.10	0.10	24289.	35.	ND	ND
2.	0.036	0.003	ND	BDL	61172.	ND	0.15	0.22	15991.	2.	ND	ND
3.	BDL	0.023	ND	0.001	20390.	ND	BDL	BDL	2920.	1.	ND	ND
4.	0.150	0.010	ND	BDL	BDL	ND	BDL	0.15	589.	1.	ND	ND
5.	0.018	0.022	ND	0.003	BDL	0.02	0.06	0.02	4000.	2.	ND	ND
6.	BDL	0.024	ND	BDL	581.	0.01	0.02	0.01	4125.	ND	ND	ND
7.	0.012	0.010	0.006	0.003	ND	0.02	ND	ND	ND	ND	ND	ND
8.	0.020	0.999	ND	BDL	BDL	0.02	ND	ND	BDL	1.	ND	ND
9.	0.110	0.012	ND	BDL	1684.	0.01	ND	ND	100.	9.	ND	ND
10.	ND	0.013	ND	0.030	204.	0.01	ND	ND	55.	8.	ND	ND
11.	ND	ND	ND	BDL	130.	ND	ND	ND	BDL	BDL	ND	ND
12.	0.023	0.012	ND	BDL	75.	BDL	ND	ND	7.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-4. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 22 WHICH CONTAINED SLUDGE 900 TREATED BY PROCESS B.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	7.	4.5000	11.4	3600.	BDL	BDL	95.0	BDL	0.030	ND	0.0011	BDL	0.008
2.	14.	2.4095	11.0	2800.	BDL	BDL	71.4	BDL	0.001	2.100	BDL	BDL	BDL
3.	21.	2.4738	11.1	2580.	BDL	BDL	49.5	BDL	BDL	0.699	BDL	BDL	BDL
4.	28.	1.7730	11.1	2150.	BDL	BDL	80.1	BDL	0.002	0.500	BDL	BDL	BDL
5.	42.	2.0654	11.0	2090.	BDL	BDL	70.0	0.0005	0.002	0.045	0.0018	0.0	BDL
6.	56.	2.0998	10.7	1320.	BDL	BDL	12.9	BDL	ND	0.018	BDL	BDL	BDL
7.	91.	2.5472	9.5	1300.	BDL	0.0004	32.2	BDL	0.001	0.063	0.0002	BDL	0.010
8.	126.	2.2891	10.6	200.	BDL	BDL	70.9	BDL	0.003	0.140	BDL	BDL	BDL
9.	161.	1.7385	9.3	1500.	BDL	BDL	172.0	BDL	BDL	0.090	0.0024	0.1	BDL
10.	224.	1.7730	9.4	984.	0.002	0.0005	93.3	0.0016	0.001	BDL	0.0002	ND	0.001
11.	273.	3.2353	9.0	1090.	ND	ND	15.1	0.0003	BDL	0.050	ND	BDL	ND
12.	365.	3.4074	9.0	1100.	0.017	BDL	57.0	BDL	BDL	0.066	0.0002	0.0	BDL
13.	498.	4.5000	8.6	1100.	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	611.	4.5000	11.0	1100.	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	735.	4.5000	7.5	880.	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-4. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	21,000	0.007	ND	0.040	115.	ND	BDL	0.20	1094.	80.	ND	ND
2.	19,000	BDL	ND	BDL	100.	0.31	0.40	0.45	791.	80.	ND	ND
3.	9,300	0.002	ND	0.003	5.	ND	BDL	ND	750.	70.	ND	ND
4.	7,300	0.003	ND	BDL	285.	ND	BDL	0.50	714.	60.	ND	ND
5.	5,200	0.030	ND	0.006	15.	0.09	BDL	0.01	675.	80.	ND	ND
6.	3,100	0.004	ND	BDL	BDL	0.05	BDL	BDL	475.	ND	ND	ND
7.	2,394	BDL	0.007	0.003	ND	0.03	ND	ND	ND	ND	ND	ND
8.	2,095	0.002	ND	BDL	32.	0.05	0.14	0.01	441.	55.	ND	ND
9.	1,700	0.007	ND	BDL	63.	0.05	0.04	0.02	312.	11.	ND	ND
10.	1,600	BDL	ND	0.030	BDL	0.05	ND	ND	450.	3.	ND	ND
11.	ND	ND	ND	ND	BDL	0.01	ND	ND	322.	BDL	ND	ND
12.	1,649	BDL	ND	BDL	BDL	ND	ND	ND	270.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-5. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 47 WHICH CONTAINED UNTREATED SLUDGE 800.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	1.	0.9106	8.6	60000.	ND	0.	310.0	BDL	ND	1.200	ND	1.6	ND
2.	8.	4.5000	9.6	130000.	ND	0.0008	548.2	ND	ND	2.700	0.0280	0.8	BDL
3.	14.	3.6999	9.6	88000.	ND	0.0001	544.5	ND	ND	0.039	0.0084	0.6	ND
4.	21.	4.0612	9.0	2600.	ND	ND	569.3	0.0003	ND	0.045	0.0064	0.9	BDL
5.	28.	3.2525	7.1	2390.	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	39.	1.7041	8.0	240.	ND	ND	578.9	BDL	ND	0.003	0.0080	4.1	0.000
7.	63.	3.0977	7.1	2000.	ND	ND	592.2	ND	0.003	0.025	0.0005	1.6	ND
8.	91.	4.5000	6.2	1960.	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	126.	4.0095	6.6	2000.	ND	ND	680.0	ND	BDL	0.013	ND	3.5	ND
10.	189.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	245.	3.5622	7.3	2050.	ND	0.0005	429.1	0.0004	0.002	0.038	0.0005	11.4	0.009
12.	353.	3.0633	7.1	2500.	0.029	0.1260	641.0	0.0009	BDL	0.036	0.0045	5.9	0.008
13.	451.	2.8912	7.1	2700.	BDL	BDL	587.0	0.0007	0.030	0.021	0.0052	BDL	0.025
14.	569.	1.3600	7.4	2700.	0.	0.1310	559.6	0.0422	0.	0.045	0.0077	7.1	0.018
15.	708.	2.0310	7.4	2600.	BDL	BDL	531.3	0.0005	BDL	0.008	0.0125	60.9	0.030
16.	814.	1.8590	7.2	2600.	BDL	BDL	559.8	BDL	0.001	0.004	0.0069	98.1	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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TABLE C-5. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	ND	7.100	ND	ND	ND	0.01	0.75	0.05	32789.	0.	54.	ND
2.	ND	0.449	ND	ND	24000.	ND	1.20	0.	21991.	ND	54.	ND
3.	0.015	0.002	ND	0.030	177.	0.01	BDL	0.	2190.	0.	BDL	57.
4.	ND	0.006	0.013	ND	68.	ND	BDL	BDL	1389.	0.	8.	53.
5.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	ND	0.003	ND	0.	20.	BDL	ND	ND	1345.	ND	5.	ND
7.	ND	ND	ND	ND	35.	BDL	ND	ND	1600.	ND	ND	ND
8.	ND	ND	ND	ND	BDL	BDL	ND	ND	2066.	ND	ND	ND
9.	ND	0.004	ND	ND	ND	0.15	ND	ND	1372.	BDL	ND	ND
10.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	ND	ND	ND	ND	37.	BDL	ND	ND	1691.	5.	ND	ND
12.	1.159	ND	ND	ND	35.	ND	ND	ND	1720.	2.	ND	ND
13.	0.008	BDL	ND	BDL	BDL	ND	ND	ND	1693.	1.	ND	ND
14.	0.990	0.	0.	0.072	10.	ND	ND	ND	2094.	ND	ND	ND
15.	BDL	BDL	BDL	BDL	20.	ND	ND	ND	1800.	ND	ND	ND
16.	0.	ND	BDL	BDL	20.	ND	ND	ND	1597.	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-6. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 58 WHICH CONTAINED UNTREATED SLUDGE 200.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	1.	0.1385	6.6	ND	ND	BDL	420.0	0.5300	0.999	0.380	0.1000	620.0	0.790
2.	8.	0.2762	8.2	ND	ND	ND	505.2	0.7300	0.699	0.600	ND	699.5	1.422
3.	14.	0.1901	8.4	ND	BDL	0.0003	519.5	0.8400	0.090	0.319	ND	2.7	1.494
4.	21.	0.1385	8.4	ND	ND	ND	559.3	0.9998	0.090	0.400	ND	749.3	1.792
5.	28.	0.1385	8.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	39.	0.1041	8.0	4850.	ND	ND	598.9	0.8200	0.060	0.700	ND	949.4	2.264
7.	63.	0.0869	7.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	91.	0.4310	7.8	7400.	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	126.	0.5686	8.2	0.	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	189.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	245.	3.0177	8.1	7000.	ND	ND	439.1	1.4300	0.060	0.360	0.0020	1049.9	1.700
12.	353.	1.6869	8.1	10200.	0.001	ND	721.0	0.5291	0.153	0.286	0.0004	709.9	2.798
13.	451.	1.6869	8.0	9400.	BDL	BDL	627.0	1.0997	0.088	0.387	0.0009	699.9	2.200
14.	569.	1.3945	8.1	10000.	0.001	0.0430	539.6	1.2772	0.067	0.590	0.0015	879.8	2.409
15.	708.	1.8590	7.8	9200.	0.019	BDL	438.3	0.8087	0.123	0.874	0.0177	720.0	1.869
16.	814.	2.1170	7.8	8800.	BDL	BDL	502.8	0.7535	0.117	1.004	0.0012	643.8	1.730

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-6. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	ND	1.800	ND	0.020	ND	ND	2.70	0.05	5489.	ND	ND	ND
2.	0.700	1.499	ND	ND	163.	ND	0.50	0.10	7241.	ND	ND	ND
3.	1.210	1.498	ND	0.070	ND	ND	ND	ND	ND	ND	ND	ND
4.	0.032	1.399	0.066	0.050	ND	ND	ND	ND	ND	ND	ND	ND
5.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	ND	1.000	ND	0.080	ND	ND	ND	ND	ND	ND	ND	ND
7.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	0.200	1.200	ND	0.	266.	ND	ND	ND	14241.	BDL	ND	ND
12.	0.480	2.300	ND	0.092	245.	ND	ND	ND	3940.	BDL	ND	ND
13.	0.177	1.300	ND	0.065	200.	ND	ND	ND	7793.	1.	ND	ND
14.	0.950	0.399	0.016	0.184	240.	ND	ND	ND	1494.	2.	ND	ND
15.	0.150	0.298	0.058	0.011	250.	ND	ND	ND	14750.	ND	ND	ND
16.	0.172	ND	ND	BDL	220.	ND	ND	ND	9497.	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-7. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 84 WHICH CONTAINED SLUDGE 800 TREATED BY PROCESS A.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	14.	1.5149	10.4	50000.	0.033	BDL	1930.0	BDL	0.025	0.209	0.0021	8.8	BDL
2.	21.	2.2375	10.1	3800.	0.020	0.0025	1019.2	BDL	0.159	0.006	0.0016	11.2	1.822
3.	28.	2.0310	9.2	25000.	0.018	0.0060	395.5	0.0200	0.130	0.537	0.0008	5.7	BDL
4.	35.	2.0310	10.2	19000.	0.018	0.0005	683.3	0.1668	0.014	0.105	0.0005	7.4	BDL
5.	56.	3.0805	8.3	8700.	0.011	BDL	410.0	0.0200	0.010	0.060	0.0009	1.7	0.002
6.	77.	1.7385	7.4	10600.	0.009	BDL	718.9	BDL	0.003	0.028	0.0017	4.7	BDL
7.	133.	3.3214	8.9	10620.	0.016	BDL	429.2	0.0096	BDL	0.052	0.0006	1.6	BDL
8.	161.	3.4074	8.1	13000.	0.019	0.0050	219.3	0.0052	0.061	0.014	0.0001	1.1	BDL
9.	196.	2.8052	8.8	11010.	0.018	0.0030	550.0	0.0018	0.039	0.060	0.0011	2.4	BDL
10.	259.	4.5000	8.1	2800.	0.005	BDL	248.3	0.0027	0.080	BDL	0.0009	BDL	0.002
11.	329.	4.5000	7.0	1000.	0.002	BDL	84.1	0.0160	BDL	0.005	BDL	0.5	BDL
12.	392.	4.5000	7.8	2900.	0.007	BDL	287.0	0.0057	BDL	BDL	0.0004	1.3	0.005
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-7. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	1.300	0.140	0.700	0.004	ND	ND	ND	ND	ND	ND	ND	ND
2.	0.051	0.044	0.092	BDL	ND	ND	ND	ND	ND	ND	ND	ND
3.	0.300	BDL	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
4.	0.330	0.010	ND	BDL	ND	0.01	ND	ND	ND	ND	ND	ND
5.	0.140	0.015	ND	BDL	2864.	ND	ND	ND	3200.	BDL	ND	ND
6.	0.120	0.006	ND	BDL	3354.	ND	ND	ND	3000.	ND	ND	ND
7.	BDL	0.001	ND	0.006	3967.	0.01	ND	ND	4050.	BDL	ND	ND
8.	0.032	0.025	ND	BDL	2536.	0.01	ND	ND	4091.	ND	ND	ND
9.	0.015	BDL	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
10.	0.026	0.600	ND	0.002	275.	BDL	ND	ND	1050.	3.	ND	ND
11.	BDL	BDL	0.012	BDL	145.	ND	ND	ND	311.	BDL	ND	ND
12.	BDL	0.043	0.006	BDL	175.	ND	ND	ND	1260.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-8. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 86 WHICH CONTAINED SLUDGE 200 TREATED BY PROCESS B.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	7.	4.5000	11.9	20000.	BDL	0.0001	282.0	BDL	24.799	13.600	0.0009	0.1	0.020
2.	14.	4.5000	11.6	8800.	BDL	0.0008	376.2	BDL	12.299	4.000	0.0003	BDL	BDL
3.	21.	2.2375	11.0	6400.	0.004	0.0041	419.5	BDL	6.400	2.399	0.0001	BDL	BDL
4.	28.	2.0482	11.1	4880.	BDL	0.0022	462.3	0.0006	4.500	2.000	0.0032	BDL	BDL
5.	42.	2.2375	11.0	4200.	BDL	0.0008	480.0	BDL	0.003	2.100	0.0028	0.1	BDL
6.	56.	2.4611	12.0	3000.	BDL	0.0010	618.9	BDL	2.850	1.500	BDL	BDL	BDL
7.	91.	1.6869	7.5	2900.	BDL	0.0008	559.2	0.0017	2.000	1.300	0.0005	BDL	BDL
8.	126.	2.3751	10.0	2500.	BDL	BDL	498.3	BDL	3.150	2.800	BDL	BDL	BDL
9.	161.	1.7730	8.6	2200.	BDL	0.0020	660.0	BDL	0.968	2.550	BDL	0.2	BDL
10.	224.	2.0310	9.6	2200.	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	273.	3.0977	6.9	2300.	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.	365.	4.5000	10.0	2300.	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	498.	4.5000	7.6	2300.	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	611.	3.9235	9.5	2000.	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	735.	4.5000	7.7	1800.	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-8. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	0.168	0.384	ND	0.070	495.	ND	ND	0.07	14489.	4.	ND	ND
2.	0.163	BDL	ND	BDL	305.	1.94	0.08	0.11	8791.	30.	ND	ND
3.	0.	0.004	ND	0.018	489.	ND	BDL	BDL	4100.	45.	ND	ND
4.	0.036	0.011	ND	BDL	51.	ND	0.	0.40	284.	1.	ND	ND
5.	0.034	BDL	ND	0.003	45.	0.44	0.20	0.02	2580.	2.	ND	ND
6.	0.025	BDL	ND	BDL	15.	0.39	0.06	0.04	2200.	ND	ND	ND
7.	0.017	BDL	0.041	0.002	ND	0.34	ND	ND	ND	ND	ND	ND
8.	0.005	BDL	ND	BDL	BDL	0.33	ND	ND	1781.	2.	ND	ND
9.	0.008	BDL	ND	BDL	65.	0.36	ND	ND	1867.	15.	ND	ND
10.	ND	ND	ND	ND	BDL	0.39	ND	ND	1500.	2.	ND	ND
11.	ND	ND	ND	ND	BDL	ND	ND	ND	1401.	BDL	ND	ND
12.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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TABLE C-9. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 102 WHICH CONTAINED SLUDGE 200 TREATED BY PROCESS D.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	7.	2.1515	7.1	24.	0.001	BDL	1.2	BDL	BDL	0.035	ND	BDL	0.004
2.	14.	2.0826	7.1	160.	0.010	BDL	3.5	BDL	BDL	0.028	BDL	BDL	BDL
3.	21.	1.8590	7.3	40.	BDL	0.0004	0.5	BDL	0.001	0.036	BDL	ND	BDL
4.	28.	1.8590	7.0	51.	BDL	BDL	1.3	2.3998	0.001	0.002	BDL	ND	BDL
5.	42.	1.5493	7.4	63.	0.004	BDL	15.0	0.0036	BDL	0.003	BDL	0.1	0.005
6.	56.	1.8590	7.2	42.	0.008	ND	BDL	BDL	0.	BDL	BDL	BDL	BDL
7.	91.	2.2891	7.1	16.	BDL	0.0002	ND	0.0006	0.005	0.015	0.0007	ND	BDL
8.	112.	1.6181	7.4	33.	BDL	BDL	0.8	0.0017	BDL	0.017	BDL	BDL	BDL
9.	147.	1.5321	7.2	25.	BDL	BDL	2.4	BDL	BDL	BDL	BDL	BDL	BDL
10.	210.	3.3214	7.1	33.	0.001	0.0002	1.2	0.0017	BDL	BDL	BDL	ND	BDL
11.	273.	2.2719	7.1	42.	0.001	BDL	3.0	0.0020	BDL	0.038	BDL	0.1	BDL
12.	364.	4.5000	6.4	76.	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

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EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE C-9. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	0.015	ND	ND	ND	BDL	BDL	18.80	ND	BDL	50.	ND	ND
2.	BDL	BDL	ND	BDL	15.	BDL	ND	BDL	ND	ND	BDL	BDL
3.	BDL	BDL	ND	BDL	15.	BDL	BDL	BDL	450.	ND	BDL	53.
4.	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	69.	30.	BDL	127.
5.	0.006	BDL	ND	BDL	ND	BDL	ND	ND	ND	ND	2.	ND
6.	BDL	0.001	ND	BDL	ND	ND	0.02	BDL	BDL	1.	ND	95.
7.	BDL	0.002	ND	0.010	ND	0.07	0.01	BDL	ND	ND	1.	63.
8.	BDL	BDL	ND	BDL	BDL	0.00	0.07	0.01	BDL	8.	6.	ND
9.	BDL	BDL	ND	0.014	BDL	BDL	ND	ND	442.	1.	ND	ND
10.	BDL	0.400	ND	BDL	BDL	ND	ND	ND	9.	10.	ND	ND
11.	0.001	BDL	ND	BDL	BDL	ND	0.02	BDL	1.	ND	ND	ND
12.	ND	ND	ND	ND	BDL	ND	ND	ND	11.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-10. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 110 WHICH CONTAINED SLUDGE 300 TREATED BY PROCESS B.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	7.	4.5000	12.6	30000.	BDL	BDL	108.0	BDL	0.020	0.025	0.0012	0.0	0.016
2.	14.	3.3214	12.5	19000.	BDL	BDL	168.1	BDL	0.047	0.006	0.0003	BDL	BDL
3.	21.	2.6160	11.9	11400.	0.003	BDL	269.5	BDL	0.006	BDL	0.0003	BDL	BDL
4.	28.	1.9966	12.0	9400.	BDL	BDL	351.3	0.0083	0.017	0.004	0.0020	BDL	BDL
5.	42.	2.3579	11.9	11400.	BDL	BDL	452.0	0.0070	0.011	0.006	0.0038	BDL	0.001
6.	56.	2.2375	12.2	6500.	BDL	BDL	618.9	BDL	0.005	0.002	BDL	BDL	BDL
7.	91.	2.5472	11.6	6000.	BDL	0.0004	549.2	0.	0.004	0.006	0.0001	BDL	BDL
8.	126.	1.9450	11.4	5200.	BDL	BDL	445.3	BDL	0.063	0.005	BDL	BDL	BDL
9.	161.	3.3235	11.0	4600.	BDL	BDL	450.0	BDL	BDL	BDL	BDL	0.1	BDL
10.	224.	1.9450	10.7	760.	BDL	BDL	88.3	0.0024	BDL	BDL	BDL	ND	BDL
11.	273.	4.5000	11.2	3900.	ND	ND	409.1	BDL	ND	BDL	ND	0.	ND
12.	365.	4.5000	10.0	2600.	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	498.	4.5000	8.4	140.	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	611.	4.0268	8.3	170.	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	735.	3.2353	9.5	700.	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-10. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	0.037	0.091	ND	0.070	BDL	ND	529.80	169.80	BDL	1.	ND	ND
2.	0.007	BDL	ND	BDL	BDL	0.12	1190.00	90.00	BDL	15.	ND	ND
3.	BDL	0.028	ND	0.008	87.	ND	743.40	37.90	8.	1.	ND	ND
4.	0.015	0.025	ND	BDL	10.	ND	221.80	29.50	ND	1.	ND	ND
5.	0.013	0.030	ND	0.005	BDL	0.14	418.00	20.00	8.	1.	ND	ND
6.	0.010	0.003	ND	BDL	40.	0.04	100.20	6.80	8.	ND	ND	ND
7.	0.009	0.025	0.003	0.003	ND	0.07	ND	ND	ND	ND	ND	ND
8.	BDL	0.899	ND	BDL	BDL	0.04	ND	ND	BDL	1.	ND	ND
9.	BDL	0.010	ND	0.001	83.	0.00	ND	ND	BDL	5.	ND	ND
10.	0.130	BDL	ND	BDL	BDL	0.01	ND	ND	BDL	2.	ND	ND
11.	ND	ND	ND	ND	BDL	ND	ND	ND	BDL	BDL	ND	ND
12.	ND	ND	ND	ND	BDL	ND	ND	ND	16.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-11. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 113 WHICH CONTAINED SLUDGE 300 TREATED BY PROCESS A.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	14.	1.8590	10.1	9000.	0.012	0.0013	1090.0	BDL	0.041	0.076	BDL	4.7	0.001
2.	21.	2.3751	11.2	500.	0.012	0.0004	239.1	0.1160	0.099	0.037	BDL	2.5	0.922
3.	28.	2.1170	8.9	3600.	0.008	0.0020	200.5	BDL	0.020	ND	0.0003	0.8	BDL
4.	35.	2.3751	9.9	2800.	0.011	BDL	1279.3	0.2258	0.018	0.038	BDL	1.4	BDL
5.	56.	2.2203	8.3	2900.	0.010	BDL	250.0	0.0700	0.025	0.013	0.0003	1.0	BDL
6.	77.	1.8590	7.8	2300.	0.008	BDL	248.9	0.	0.011	0.007	BDL	1.0	BDL
7.	133.	1.6869	8.5	2300.	0.024	BDL	199.2	BDL	BDL	0.008	BDL	0.2	BDL
8.	161.	3.2214	8.7	2680.	0.014	BDL	139.3	0.0011	0.030	0.005	BDL	0.7	BDL
9.	196.	2.7192	8.6	2150.	0.008	BDL	250.0	BDL	0.020	BDL	BDL	0.8	0.005
10.	259.	3.1493	7.8	1500.	0.007	0.0470	238.3	0.1000	0.026	ND	BDL	BDL	BDL
11.	329.	3.4074	8.4	1800.	0.002	BDL	349.1	0.0200	BDL	0.005	0.0002	0.9	BDL
12.	392.	4.5000	8.1	1900.	0.004	BDL	279.0	0.0174	BDL	BDL	BDL	0.9	BDL
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-11. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TUC (PPM)	CUD (PPM)
1.	0.111	0.026	0.072	0.002	ND	ND	ND	ND	ND	ND	ND	ND
2.	0.051	0.013	0.073	BDL	ND	ND	ND	ND	ND	ND	ND	ND
3.	0.020	0.000	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
4.	0.050	BDL	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
5.	0.020	0.001	ND	BDL	31.	0.11	ND	ND	1275.	0.	ND	ND
6.	0.012	0.001	ND	BDL	32.	0.08	ND	ND	1300.	5.	ND	ND
7.	0.005	BDL	ND	0.006	5.	0.11	ND	ND	1075.	BDL	ND	ND
8.	0.027	0.003	ND	BDL	3.	ND	ND	ND	1191.	0.	ND	ND
9.	0.018	0.003	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
10.	0.044	0.002	ND	1.640	5.	ND	ND	ND	750.	1.	ND	ND
11.	0.014	BDL	0.011	BDL	BDL	ND	ND	ND	791.	BDL	ND	ND
12.	0.003	BDL	0.006	BDL	30.	ND	ND	ND	780.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-12. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 122 WHICH CONTAINED SLUDGE 200 TREATED BY PROCESS C.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	7.	2.1687	4.1	15500.	BDL	4.2098	283.0	20.9300	299.999	700.000	0.0030	570.0	6.300
2.	14.	2.1687	4.3	11100.	BDL	4.4400	339.2	14.9700	129.999	800.000	0.0040	359.5	2.822
3.	21.	1.9622	4.4	9400.	BDL	3.4700	365.5	15.9800	78.000	669.999	BDL	379.5	4.044
4.	28.	3.1837	4.5	4450.	BDL	2.0000	312.3	8.4998	16.000	30.000	BDL	204.3	2.392
5.	42.	2.1515	5.0	5700.	BDL	2.0000	410.0	9.0000	20.000	310.000	ND	230.0	1.500
6.	56.	3.0633	4.5	2500.	BDL	0.7500	263.9	3.1700	6.000	180.000	BDL	59.4	0.886
7.	91.	1.6009	4.8	4000.	0.010	1.5900	689.2	5.9974	7.000	240.000	BDL	109.7	1.600
8.	126.	1.9450	5.0	3300.	BDL	1.1500	300.3	5.2975	3.900	115.000	BDL	145.0	0.577
9.	147.	1.7557	5.4	2500.	BDL	1.0300	560.0	4.3972	2.098	159.990	BDL	59.5	0.760
10.	210.	3.4934	5.0	2250.	BDL	1.0600	408.3	3.4000	1.990	179.060	BDL	52.8	0.796
11.	266.	3.1493	4.6	2700.	ND	ND	529.1	2.4000	ND	150.000	ND	30.9	ND
12.	364.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-12. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	123,000	0,700	ND	368,000	60.	0,07	ND	ND	13789.	30.	ND	ND
2.	69,500	0,239	ND	200,000	50.	ND	ND	ND	10391.	40.	ND	ND
3.	69,000	0,136	ND	180,000	51.	0,10	ND	ND	115.	9.	ND	ND
4.	36,000	BDL	ND	104,000	20.	ND	ND	ND	6489.	1.	ND	ND
5.	38,000	ND	ND	ND	30.	0,07	ND	ND	5500.	50.	ND	ND
6.	11,000	0,020	ND	38,980	10.	109,99	ND	ND	4250.	ND	ND	ND
7.	21,994	0,031	ND	73,000	10.	0,09	ND	ND	340.	7.	2800.	7005.
8.	12,095	0,036	ND	50,750	ND	0,13	ND	ND	ND	ND	ND	4692.
9.	12,200	0,030	ND	38,484	10.	0,06	ND	ND	2117.	8.	2600.	5078.
10.	8,820	BDL	ND	39,300	BDL	0,16	ND	ND	1800.	1.	1900.	6977.
11.	ND	ND	ND	ND	BDL	ND	ND	ND	1871.	BDL	1700.	6210.
12.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-13. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 123 WHICH CONTAINED UNTREATED SLUDGE 300.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	1.	0.3622	10.9	24800.	ND	ND	ND	ND	ND	0.050	ND	0.2	ND
2.	8.	0.2589	12.4	ND	ND	0.0002	0.9	0.0100	0.001	0.040	ND	BDL	0.122
3.	14.	0.3450	12.2	23000.	6.000	ND	ND	0.	0.004	0.005	ND	ND	0.003
4.	21.	0.2935	12.4	21000.	ND	ND	1.7	0.0498	ND	0.040	0.0021	BDL	BDL
5.	28.	0.2245	12.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	39.	0.1041	11.9	23000.	0.002	ND	1.2	0.0200	ND	0.080	ND	ND	0.019
7.	63.	0.1901	12.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	91.	0.9987	12.0	21500.	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	126.	1.3428	12.1	25000.	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	189.	2.5472	12.4	21000.	0.002	ND	BDL	0.0148	0.003	BDL	ND	1.2	ND
11.	245.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.	353.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	451.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	569.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	708.	2.0310	9.4	10000.	0.012	BDL	BDL	0.0049	BDL	BDL	0.0569	BDL	0.
16.	814.	1.6869	8.6	8000.	BDL	BDL	85.7	0.0061	0.001	BDL	BDL	BDL	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-13. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	ND	ND	0,007	0,040	ND	ND	919,80	279,80	245.	0.	144.	472.
2.	2,900	0,019	ND	0,030	5.	ND	1120,00	280,00	181.	ND	ND	ND
3.	0,300	0,019	ND	ND	704.	ND	2,25	13,10	101.	0.	ND	ND
4.	0,200	0,018	0,011	ND	ND	ND	ND	ND	ND	ND	ND	ND
5.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	0,400	0,019	ND	0,050	ND	ND	ND	ND	ND	ND	ND	ND
7.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	0,670	0,002	ND	ND	47.	0,01	ND	ND	16500.	1.	ND	ND
11.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	0.201	0,002	0,020	BDL	BDL	ND	ND	ND	10.	15.	ND	ND
16.	0,113	ND	0,004	BDL	BDL	ND	ND	ND	8.	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-14. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 124 WHICH CONTAINED UNTREATED SLUDGE 900.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	1.	0.2762	6.5	3610.	ND	BDL	850.0	BDL	0.005	0.010	ND	59.0	0.090
2.	8.	0.2589	8.2	ND	ND	0.0001	860.2	BDL	0.899	0.004	ND	56.5	0.062
3.	14.	0.3278	8.3	3200.	ND	0.0003	784.5	BDL	ND	0.005	ND	2.1	0.075
4.	21.	0.2589	8.1	3000.	ND	ND	819.3	0.0003	ND	0.010	ND	59.5	0.075
5.	28.	0.2245	8.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	39.	0.1385	7.9	3800.	0.002	ND	1058.9	BDL	ND	0.013	ND	113.4	0.053
7.	63.	0.2073	7.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	91.	0.9299	7.2	2540.	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	126.	1.2568	7.8	3000.	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	189.	1.6869	7.8	2700.	0.008	ND	535.3	0.0012	ND	BDL	ND	84.4	0.040
11.	245.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.	353.	1.6869	6.8	3400.	0.008	ND	631.0	0.0056	0.047	BDL	ND	70.9	0.114
13.	451.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	569.	1.5149	6.4	3500.	BDL	0.1300	529.6	BDL	BDL	BDL	BDL	85.6	0.095
15.	708.	1.6869	8.1	3100.	0.014	BDL	497.3	0.0005	0.003	0.001	0.0007	97.0	0.068
16.	814.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-14. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	ND	0.035	ND	ND	ND	ND	2.00	0.05	2069.	BDL	ND	ND
2.	0.018	0.013	ND	ND	43.	ND	0.40	0.10	2191.	ND	ND	ND
3.	0.040	0.002	ND	0.040	22.	ND	BDL	1.80	1625.	ND	ND	ND
4.	ND	0.050	0.013	ND	ND	ND	ND	ND	ND	ND	ND	ND
5.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6.	ND	0.003	ND	0.030	ND	ND	ND	ND	ND	ND	ND	ND
7.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10.	0.050	0.001	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12.	1.179	ND	ND	0.069	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	0.950	0.	0.001	BDL	20.	ND	ND	ND	2794.	ND	ND	ND
15.	0.022	0.001	0.011	BDL	20.	ND	ND	ND	2200.	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIR. EPA FORM 267)
TYPING GUIDE SHEET

TABLE C-15. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 134 WHICH CONTAINED SLUDGE 700 TREATED BY PROCESS C.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	LD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	7.	1,6181	4,8	14790.	0,002	ND	238,0	96,9300	4,699	16,000	0,0120	1620,0	77,000
2.	14.	2,2719	4,9	10200.	0,017	BDL	219,1	57,9700	19,999	4,800	0,0480	669,5	7,922
3.	21.	2,2547	5,8	7500.	BDL	BDL	237,5	41,9800	8,600	2,099	0,0082	609,5	37,295
4.	28.	2,0482	5,7	5800.	BDL	BDL	199,3	7,9998	3,400	1,600	0,0095	382,3	24,992
5.	42.	2,2891	6,4	5400.	BDL	0,5000	240,0	37,0000	20,000	1,500	ND	410,0	28,000
6.	56.	1,9450	4,5	3500.	0,004	BDL	268,9	29,9700	1,200	1,360	0,0003	219,4	25,986
7.	91.	1,8590	5,2	3900.	BDL	0,0050	315,2	38,9974	1,500	0,900	0,0015	419,7	16,000
8.	126.	2,2031	5,7	3400.	BDL	0,0004	407,3	50,5975	0,420	1,880	BDL	207,0	22,897
9.	147.	1,6869	6,0	2290.	BDL	BDL	450,0	43,5972	0,338	1,090	0,0004	139,0	16,800
10.	210.	3,3730	6,0	1900.	BDL	0,0005	358,3	33,0000	0,342	BDL	BDL	70,8	14,500
11.	266.	2,7364	6,1	2200.	ND	ND	419,1	23,0000	ND	0,770	ND	73,9	ND
12.	364.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	364.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-15. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	5.700	4.200	ND	30.000	50.	190.00	ND	ND	15489.	25.	ND	ND
2.	3.600	3.499	ND	15.000	40.	0.10	ND	ND	9191.	65.	ND	ND
3.	2.900	0.998	ND	10.000	51.	0.16	ND	ND	650.	1.	ND	ND
4.	1.800	0.003	ND	5.800	30.	ND	ND	ND	4989.	5.	ND	ND
5.	2.000	ND	ND	ND	10.	0.05	ND	ND	5000.	40.	ND	ND
6.	1.300	1.000	ND	0.480	20.	0.15	ND	ND	4000.	ND	ND	ND
7.	BDL	0.458	ND	6.200	BDL	0.10	ND	ND	33.	1.	2600.	4100.
8.	1.695	BDL	ND	7.230	ND	0.13	ND	ND	ND	ND	ND	3768.
9.	1.300	3.200	ND	6.184	BDL	ND	ND	ND	1917.	9.	2200.	2692.
10.	2.020	BDL	ND	6.800	BDL	ND	ND	ND	1450.	1.	1870.	6899.
11.	ND	ND	ND	ND	BDL	ND	ND	ND	1441.	BDL	2400.	518.
12.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-16. PARAMETERS OF LEACHATES FROM PRIORITY COLUMN 139 WHICH CONTAINED SLUDGE 200 TREATED BY PROCESS A.

SAMPLE SEQ NUM	TIME (DAYS)	VOL (LITERS)	PH	COND (MMHOS/CM)	AS (PPM)	BE (PPM)	CA (PPM)	CD (PPM)	CR (PPM)	CU (PPM)	HG (PPM)	MG (PPM)	MN (PPM)
1.	14.	1.6869	9.3	14000.	0.007	0.0035	1210.0	BDL	2.499	3.600	BDL	9.7	0.002
2.	21.	1.9794	9.4	900.	0.002	BDL	460.2	0.0750	1.599	1.900	BDL	2.6	0.922
3.	28.	1.6869	8.1	6000.	0.003	0.0010	569.5	0.	0.800	1.799	0.0006	4.9	BDL
4.	35.	1.8590	9.0	4600.	0.004	0.0005	468.3	0.0788	0.300	0.956	BDL	4.4	BDL
5.	56.	1.9794	7.4	3500.	0.002	0.0020	510.0	0.0020	0.001	1.100	0.0006	3.3	BDL
6.	77.	2.0482	7.5	3100.	0.003	0.0010	658.9	BDL	0.080	0.880	BDL	5.7	BDL
7.	133.	2.5472	8.3	3080.	0.002	BDL	509.2	BDL	0.041	0.463	BDL	2.0	0.002
8.	161.	4.5000	8.6	2000.	0.004	0.0010	509.3	BDL	0.060	0.009	BDL	3.1	BDL
9.	196.	0.8267	8.1	2950.	0.006	BDL	540.0	BDL	0.055	0.200	BDL	3.2	0.002
10.	259.	4.5000	7.8	2300.	0.006	BDL	528.3	0.0007	0.226	BDL	BDL	0.9	BDL
11.	329.	3.4074	7.1	2000.	0.001	BDL	559.1	0.0012	0.241	0.100	0.0005	2.3	0.004
12.	392.	4.5000	8.3	1900.	BDL	BDL	433.0	BDL	0.059	0.176	BDL	2.4	0.
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.

TABLE C-16. CONCLUDED.

SAMPLE SEQ NUM	NI (PPM)	PB (PPM)	SE (PPM)	ZN (PPM)	CL (PPM)	CN (PPM)	N-NO3 (PPM)	N-NO2 (PPM)	SO4 (PPM)	SO3 (PPM)	TOC (PPM)	COD (PPM)
1.	0.049	0.032	0.168	0.005	ND	1.63	ND	ND	ND	ND	ND	ND
2.	0.083	0.034	0.122	BDL	ND	1.11	ND	ND	ND	ND	ND	ND
3.	0.012	0.002	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
4.	BDL	0.003	ND	0.010	ND	0.41	ND	ND	ND	ND	ND	ND
5.	BDL	0.001	ND	BDL	26.	0.33	ND	ND	3000.	BDL	ND	ND
6.	0.008	0.006	ND	BDL	26.	0.17	ND	ND	2050.	BDL	ND	ND
7.	BDL	BDL	ND	0.007	5.	0.03	ND	ND	2300.	BDL	ND	ND
8.	0.017	0.034	ND	BDL	BDL	ND	ND	ND	1641.	ND	ND	ND
9.	0.013	0.001	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND
10.	0.029	BDL	ND	0.008	BDL	ND	ND	ND	1350.	ND	ND	ND
11.	BDL	BDL	0.010	BDL	BDL	ND	ND	ND	1441.	BDL	ND	ND
12.	0.003	BDL	0.004	BDL	BDL	ND	ND	ND	1020.	BDL	ND	ND
13.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = NOT DETERMINED.
BDL = BELOW DETECTION LIMITS.